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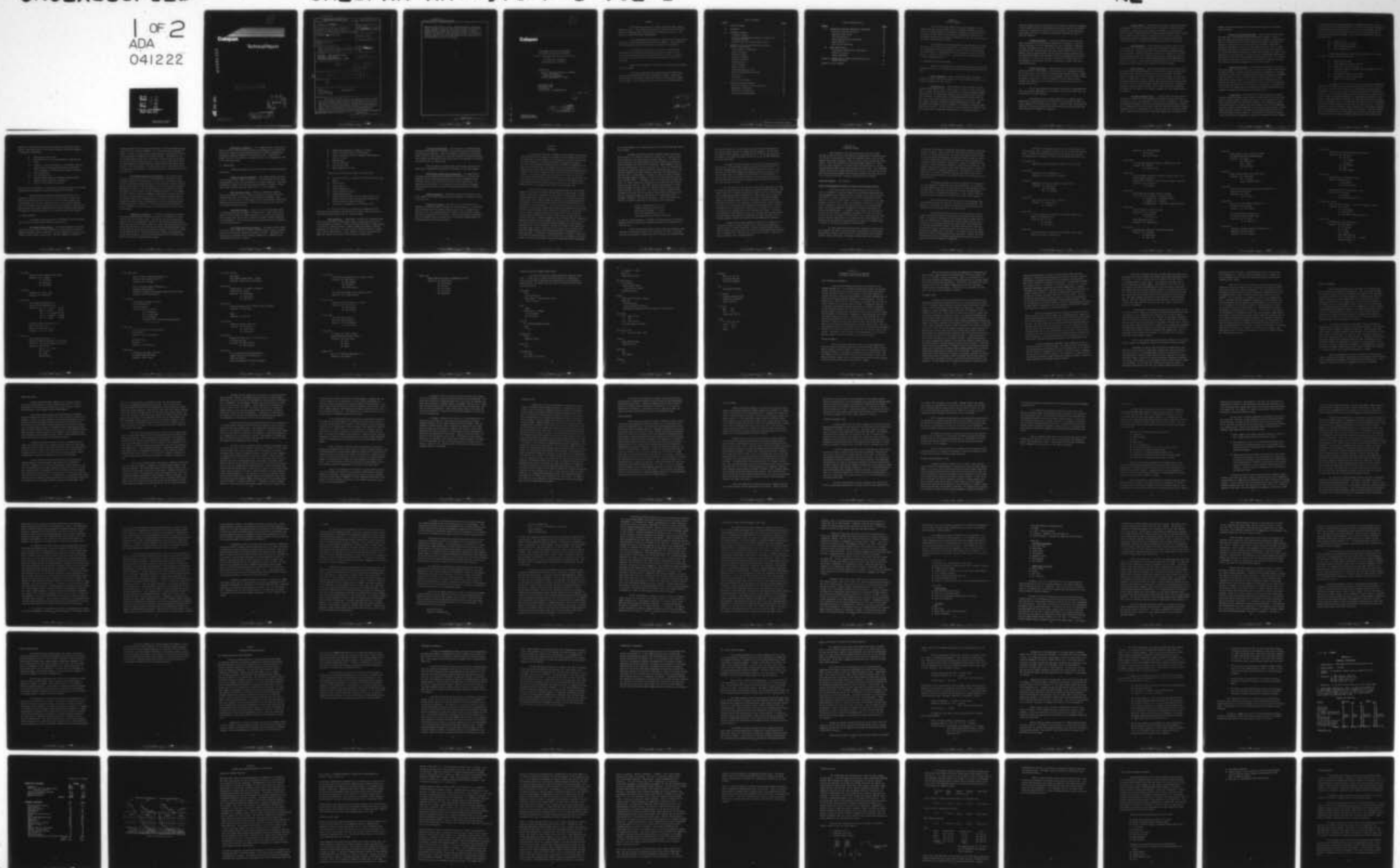

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Technical Report

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Buffalo, New York 14221

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The objective of this study was to assess the use of simulators in military tactical flight training. The assessment was made on the basis of information obtained from a literature survey and a survey of individuals in industry and government agencies who are knowledgeable about flight simulators, military tactical flight training and related matters. Forty six organizations were visited during the survey. Assessments are made of the use of simulators for training the → OVER

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following flight phases or tasks: cockpit procedures, instrument flight, emergency procedures, takeoff and landing, formation flight, aerial refueling, dynamic failures, ground attack, training of maneuver limits, recovery from uncontrolled flight, air combat and nonpilot crew stations. Other aspects of the use of simulators for aircrew training are discussed and problem areas requiring research and development effort are identified.

(1)

Calspan

AN ASSESSMENT OF THE ROLE OF SIMULATORS
IN MILITARY TACTICAL FLIGHT TRAINING
(Volume I Assessment Based on Survey Interviews)

C.R. Chalk and R. Wasserman

Calspan Report No. AK-5970-F-1

Prepared for:

Office of Assistant Secretary of Defense
Office of the Director,
Planning and Evaluation
Pentagon, Washington D.C. 20301

30 September 1976
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15 April 1976 - 30 September 1976

Calspan Corporation
Buffalo, New York 14221

PREFACE

This document was prepared by Calspan Corporation under Contract MDS903-76-C-0274. The contract was performed for the Office of the Assistant Secretary of Defense, Office of the Director, Planning and Evaluation. The project was monitored by Maj. George Burkley.

In the performance of this contract, Calspan visited and interviewed personnel of many government agencies and private companies. The cooperation of these organizations and the individuals interviewed is acknowledged.

In preparing this report, Mr. C.R. Chalk was responsible for documenting and interpreting the conversations with individuals (and the briefing material they presented) during the survey interviews. Volume 1 of this report is primarily based on the information gathered in these survey interviews.

Volume 2 of this report is based on the literature survey performed by Mr. Wasserman.

The opinions expressed in this report are those of the authors and are not necessarily shared by the Department of Defense. Publication of this report to document the study and to promote the exchange of information and ideas in no way implies DOD sanction of the views expressed herein.

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Section I
EXECUTIVE SUMMARY

The cost of military flight training and the emphasis on fuel conservation has forced the Armed services to consider increased use of simulators for flight training. This study was performed by Calspan Corporation to provide the OASD, Office of the Director of Planning and Evaluation, an independent assessment of the status of simulators and the role they should play in military tactical flight training.

The assessment was based on information obtained from a literature survey and survey interviews with individuals in industry and government who are knowledgeable about flight simulators, military tactical flight training and related matters. Approximately forty six organizations were visited and thirty five simulators were observed. Thirteen of these simulators were flown by Calspan engineering pilots.

1.1 ASSESSMENT OF ROLE OF SIMULATORS

Based on the information obtained from these sources, the following assessments of the role of simulators for training of tactical flight crews was made.

<u>Cockpit Procedures</u> — Simple, inexpensive cockpit procedures trainers are highly effective training devices for introducing students to the cockpit environment of a new aircraft.

<u>Instrument Flight</u> — The instrument flight simulators currently available [for example, the T-2 (2F101), the TA-4 (2F90), the UH-1 (2B24) and the F-4 (2F88)] are considered to be excellent for training cockpit procedures, radio operation, fuel management, navigation and instrument flight procedures. These simulators are highly useful for supplementing the training in the aircraft and in fact permit reducing the training time in the aircraft. They do not, however, represent the aircraft flight characteristics or the flight environment well enough to permit elimination of instrument training and experience in the airplane. The best balance of training between the simulators and the airplanes must be determined from experience. The motion systems of

instrument flight simulators were generally considered to be desirable components of the simulators because the motion adds realism which results in the students treating the simulator more like they treat the airplane. Motion systems were judged highly desirable or essential by experienced operators and users of this type simulator.

Emergency Procedures – The use of simulators for training emergency procedures is a well established application of simulators. There are several advantages in favor of performing this type of training in simulators. The major advantages are safety and the fact that some emergencies cannot be experienced in the airplane unless the system failure actually occurs. The number of failure states designed into the simulator should be consistent with the training requirements and the number that can be accommodated in the training schedules. In past cases, hundreds or thousands of failure states have been designed in the simulator but only a fraction have actually been used in training application.

Takeoff and Landing – Simulators with visual displays are being used successfully to train terminal area procedures and to supplement training of the flying skills associated with ground handling, takeoff, approach, landing and rollout. They are also being used to supplement training of carrier landing and catapult launch tasks. There are frequently observed lateral control anomalies and landing sink rate performance discrepancies which should be researched and resolved.

Visual image generation and display technology is a developing field which should permit improvements in the field of view and scene detail that can be presented for landing training.

The addition of visual display capability to a simulator places significantly increased demands on the fidelity of the math model and data base used to represent the aircraft and its systems. Because of this, additional cost and effort in testing the aircraft and the simulator should be anticipated when visual displays are included in a simulator.

Formation Flight – The feasibility of using a fixed based simulator to supplement the training of formation flight techniques and skills has been demonstrated. Because the task is dynamically demanding it is necessary to minimize delays and lags introduced by sampling, digital computations and hardware. The task requires large field of view visual display of the lead aircraft. Problems were observed in prototype equipment during overtake join-ups that result from inability to judge range and range rate from the visual display.

Aerial Refueling – Aerial refueling is basically similar to formation flight but the field of view required to perform the refueling task is not as extensive. Several organizations claim development of prototype equipment which permits simulation of aerial refueling. No information is available on training effectiveness of simulators for the aerial refueling task but it appears feasible to the authors that refueling training can be supplemented by the use of simulators. Minimization of simulator delays and visual scene resolution are critical factors in the simulation of aerial refueling.

Dynamic Failures – The use of simulators may be the only feasible way to provide the training experience for failures that cannot be experienced in flight, unless the failure actually occurs, or for failures that would result in a high risk of loss of control if induced in flight. The use of simulators to train flight crews to recognize and cope with dynamic failures has been demonstrated to be feasible, however, motion and force cues have been shown to be vital aspects of the simulation of many dynamic failures. A significant problem in simulating dynamic failures may be acquisition of data describing the effects of the failure on the aircraft response and on the cockpit displays and controls.

Training of Maneuver Limits – Tactical flight crews must learn to recognize the factors that limit maneuvering performance of their aircraft so that they can fly it with confidence to the limits of its capability. The problem of adequately modeling the aircraft and acquiring the necessary data to simulate it to the degree of fidelity necessary to make the simulation useful for training operational pilots is considered to be a major one that will require much effort. There is doubt that the motion and force cueing methods used in simulators are

adequate to provide the fidelity of cues necessary for the level of training under discussion.

Recovery from Uncontrolled Flight – The Air Force has been using the Vought Corp. large amplitude moving beam simulator, LAMBS, to train A-7 pilots to recognize and recover from loss of control situations. Because flying skills are not being trained so much as emergency procedures, less fidelity is required in simulation of the aircraft during out-of-control flight than is required for simulation to train to fly near maneuver limits. Even so, complicated math models of the aircraft and extensive data are required to simulate the various spin modes and responses to control that airplanes can exhibit. Data acquisition is a major problem. The motion and force environment encountered in uncontrolled flight cannot be duplicated in ground simulators but it is believed that simulation of these factors to the extent possible is important to create the stress and confusion associated with out of control flight.

Nonpilot Crew Stations – The simulators being used to train nonpilot crew members of the S-3, E-2B and F-4 aircraft, for example, were described as highly effective. Training nonpilot crew members in simulators is analogous to the use of simulators for training pilots in cockpit procedures and instrument flight procedures. It was claimed that nonpilot crew members of the S-3 and E-2B could be trained entirely in the simulator, however, because of lack of fidelity and realism in the sensor simulation and because the realism and hazard of the flight environment can not be created in the simulator, it is necessary to use a mix of simulator and aircraft training to develop the proficiency and competence required for participation in operational units.

Ground Attack – The feasibility of using simulators for supplementing training for ground attack missions has been explored by the Navy using the TA-4 (2F90) simulator equipped with the 2B35 visual system and by the Air Force using the ASUPT, SAAC and LAMARS simulators. These feasibility studies have demonstrated that currently available equipment can be used to supplement training of ground attack fundamentals such as bombing range procedures, cockpit weapon operation procedures, and control of the many parameters involved in setting up weapon release conditions. The limitations of currently available visual systems require compromises in operational procedures and limit training

of many aspects of the ground attack missions performed by tactical aircraft. To permit training in target identification, tactics by multiple aircraft against defended ground targets, ground attack in a hostile air environment, and simulation of sensor and weapon system characteristics will require advances in visual system simulation technology. Visual system characteristics requiring improvement are:

- Field of view
- Scene detail and resolution
- Image brightness and color
- Size of gaming area.

The following simulation capabilities are desirable for training air crews to perform ground attack missions:

- Moving ground targets
- Ground defensive fire (AAA and SAM)
- Weapon impact and target damage
- Simultaneous display of ground detail and images of several airborne aircraft
- Easy change of scene or scene detail
- Simulation of weapon system sensors (Radar, FLIR, LLLTV, Laser)

Air Combat - The feasibility of using simulators for supplementing training for air combat missions has been explored by the Air Force in the TAC ACES I and II projects and by the Navy using the Northrop LAS/WAVS simulator. In addition, the Air Force has been using the McDonnell MACS III simulator to train F-15 air crews and NASA Langley has been using the DMS to perform research on the importance of fighter performance and configuration parameters for air combat. These experiences in simulating air combat demonstrate that currently available equipment can be used to supplement training of air combat fundamentals such as basic fighter maneuvers and one-on-one air combat tactics. Limitations to currently available simulators require compromises in operational procedures and limit training of more advanced aspects of air combat. A problem common to most of the simulators is that the quality and resolution of the target image at long range does not permit determining target aspect and therefore delays

decisions on initial moves which alters the operational tactics that can be trained. Other deficiencies of the various simulators that are of consequence to training are listed below.

- Restricted view to the rear
- Poor fidelity of the aircraft simulation at high angle of attack
- Inability to fly close formation or to accurately track the target because of time delays which cause control imprecision or tendency to develop a pilot induced oscillation.
- Poor altitude cues
- Poor load factor cues
- Contrast between target and background brightness makes target too easy to acquire or reacquire.
- Ability to only display one aircraft.

Because of these limitations it is necessary to use these simulators under careful supervision to avoid negative training or development of bad habits.

The most advanced air combat training simulators that will be available in the DOD in the near future are the Air Force SAAC (which has a number of identified deficiencies), the Navy 2EG air combat simulator (now in procurement, which will have capability similar to the McDonnell MACS IV) and the F-14 Weapons System Trainer (which will also be similar to the MACS IV). These simulators will permit supplementing air combat training but will probably not permit any significant reduction of air combat training in the aircraft.

1.2 RELATED SUBJECTS

In addition to assessing the role of simulators in tactical flight crew training, the study examines several related subjects.

The Airline Training Example – The training programs of the major airlines have been cited by the USAF Scientific Advisory Board, the Office of Management and Budget and the Comptroller General as examples of the use of simulators to reduce flight training costs. The study compares the transition

training program for an airline captain with the Air Force replacement training program for an F-4 aircraft commander. It is shown that the two programs are similar in extent if the Air Force training directed at preparing for IFR cross country operations is compared to the airline program. The majority of the F-4 training program (about 2/3) is directed at training related to the weapon systems and tactical missions of the F-4. There are also gross differences in the flight experience levels between the transitioning airline captain and the Pipeline Air Force RTU student. In addition, the airline crews regularly fly 50-70 hours each month whereas the Air Force operational crews may fly only 10-20 hours per month.

Full Mission and/or Part Task Simulators - The relative merits of specialized Part Task and Full Mission Simulators are discussed and the systematic approach of the ISD method is recognized as a method which should facilitate selecting the training media for a new aircraft. Caution is advised against assuming that Full Mission Simulators will by definition be capable of performing all subtasks. This assumption may turn out to be false if design requirements for the subphases are not thoroughly appreciated. As an example, the ASUPT simulator, which was intended to bring together the best that technology had to offer during the early 1970's to explore the maximum effective use of modern simulators in undergraduate pilot training, initially could not be used for formation flight training because of excessive time delays which caused pilot induced oscillations. This difficulty has since been reduced, but not eliminated, by detail attention to the reduction of time delay in the visual display.

Supplement or Substitute - The Office of Management and Budget and other government agencies advocate increased use of simulators to reduce training costs and to conserve fuel. These savings can only be realized if simulator time is substituted for flight time. The tactical training officers interviewed, however, state that flying time allotted for advanced tactical training has been reduced to a level that does not permit maintaining adequate operational readiness and if funds are invested in simulators for tactical aircraft, the justification must be to improve operational readiness by supplementing current flight training. This may increase training costs for tactical forces and will not result in significant fuel savings.

Alternatives to Simulators – It is suggested that, in the case of tactical aircraft, effort should be directed at developing ways to increase the efficiency of flight training through development of onboard instrumentation, instrumented ranges and simulation of ordinance delivery. Stimulation of sensors and use of the aircraft as a ground simulator is also suggested for ASW or early warning aircraft.

1.3 PROBLEM AREAS

A number of problem areas exist which require research and development effort.

Fidelity of Aircraft Simulation – The primary problem is acquisition of accurate data to model the aircraft. Fidelity problems can also result from compromises in the real time application of digital computers. Time delays introduced by computer cycle time and simulator hardware can result in inadequate dynamic bandwidth and poor dynamic fidelity in the simulation.

Motion and Force Cueing – Research is required to establish motion system hardware dynamic performance requirements, motion system drive algorithms and limits on time delays in the motion drive commands. There is also a need for research and development of force cueing devices, drive algorithms for these devices when used in fixed base simulators and also when used in simulators with motion systems.

Time Delays and Lags – There is a need to better define limits on time delays that can be permitted in simulator cues. These limits must be defined to permit design of computer generated visual scenes, motion systems, force cueing devices and any sensor displays that require dynamic interaction by the crewmembers. The time delay limits have significant impact on computer size and iteration rates.

Visual Image Generation and Display – The extent to which simulators can be used to train for air combat and ground attack missions is limited by the visual simulation capabilities currently available. Improvements are required in the following visual simulation capabilities. Simulator visual system deficiencies for air combat:

- Target image resolution at ranges of 2-3 miles
- Ability to display multiple aircraft images
- Ability to display aircraft at formation flight range as well as 2-3 miles
- Altitude cues
- Velocity overground
- Wide field of view
- Image brightness and color

Simulator visual system deficiencies for ground attack:

- Wide field of view in combination with high resolution scene detail
- Moving targets
- Gaming area size
- Ground defensive fire
- Image brightness and color
- Varied ground lighting
- Combined display of high resolution, wide field of view ground scene and multiple aircraft images representing attack teammates or enemy air defense
- Time delay in correspondence with aircraft motion

The technical difficulties encountered in attempting to make improvements are dependent on the combinations of image storage, generation, relaying and display hardware that is being considered.

Radar Simulation – Improvements in the ability to simulate radar images with more realism are required to permit extending the training that can be performed in simulators. Factors requiring improvement are image realism, cloud effects, atmospheric effects, clutter, jamming and landmass simulation. Simulation of radar landmass is a major problem. Problems involved in digital radar landmass simulation are: effor required to generate the digital data base, data storage and retrieval, and time delay in image display.

FLIR and LLLTV Simulation – The introduction of forward-looking infrared and low-light-level TV sensors on aircraft has posed new requirements for training and simulation. There are a number of problems yet to be solved before a FLIR or LLLTV simulation is ready for inclusion in a training simulator. This includes the definition of which sensor effects are important for training and efficient ways to simulate them.

There are additional problem areas which require attention by the organizations responsible for making use of simulators in training programs.

Certification, Modification, Revalidation – An organizational structure must be established and responsibilities defined for ensuring that simulators are kept updated to represent the aircraft, maintained in good operating condition and certified for specific training applications. The modification of simulators can be extremely costly and unless well managed and coordinated may result in extensive downtime and disruption of training schedules.

Software Management – There must be centralized control of simulator software to maintain standardization of performance of simulators located at various bases.

Transfer of Training – The problem of determining how to use a simulator in a training program continues to require attention. In the environment of official policy to increase simulator use, there is a danger of proceeding too fast, i.e. making optimistic estimates of the amount of training that can be accomplished in the simulator. The role that simulators eventually play in training of tactical aircrews will be established through transfer of training experiments and field experience.

Section II

BACKGROUND

In recent years the cost of flight training, coupled with DOD budget limits and the desire to reduce fuel consumption, have resulted in pressure on the Armed Services to make greater use of simulation to reduce flight training costs and flying hours. Studies by the Office of Management and Budget (July 1973) and the General Accounting Office (197201975) recommended that the Armed Services make maximum use of simulators for air crew training as an effective way to reduce costs and conserve fuel while maintaining high training standards. The OPEC oil embargo of 1973-74 caused fuel prices to increase by a factor of 3-1/2 which greatly increased the cost of flying training (in 1974 the Air Force flew one million fewer hours than in 1973, yet its fuel costs were increased by one billion dollars). The creation of the Federal Energy Administration resulted in another source of pressure on the Armed Services to maximize the use of simulators and to reduce aircraft flight time.

Prior to 1973, the Air Force had performed studies of the training methods being used by the Airlines and had officially directed that a Systems Approach to Training be adopted in revising flight training programs. By 1973 active programs were underway by all three services to revise their training syllabi and to shift flight training to simulators to the extent permitted by the equipment. This activity became known by the term ISD which derives from Instructional System Development. In this same time period, the services also implemented organizational changes which would define responsibility for management of research, development and acquisition of simulations. For example, the Air Force Systems Command, Aeronautical Systems Division, established the Simulator System Program Office in May 1973 and the Navy and Army had previously established a Training Equipment Center at Orlando, Florida. Significant equipment developments and procurements were underway in 1973. The Air Force had simulators for 15 aircraft models under procurement plus three advanced development first article programs to develop and evaluate a broad spectrum of wide angle visual systems. They were the F-4 Project #18, the Simulator for Air-To-Air Combat (SAAC) and the Advanced Simulator for Undergraduate Pilot Training (ASUPT). The Army had initiated procurement of Synthetic Flight Training Systems for three helicopters, two of which were to be equipped with visual systems. The Navy had simulators for eleven aircraft models under procurement

plus the development of a research facility called Aviation Wide Angle Visual System (AWAVS).

In August 1973 Deputy Secretary of Defense Clement initiated selected projects in an effort to improve the effectiveness of defense spending in relation to force structure and military capability. The Office of Assistant Secretary of Defense Manpower and Reserve Affairs was assigned to provide leadership for the project on simulators. M&RA formulated a project plan for simulators which had the objectives to (1) insure the research and development, acquisition, and utilization of simulation devices, and (2) promote the maximum use of flight simulators consistent with effectiveness of training, costs, and operations. On August 31, 1973, the Office of Management and Budget formally presented its study on increased simulator procurement to the DOD (M&RA). In September 1973, a DOD study group on flight simulators was formed by M&RA with representatives from other DOD staff offices, OMB and the Armed Services. This study group met approximately five times between September 1973 and March 1974. Special crosscut hearings on simulators were held in November 1973. The crosscut hearings consisted of presentation of the Army, the Navy and the Air Force proposed simulator investment and operations programs to OMB and DOD level staff groups (OSD(c), OSD(M&RA), OSD(DDR&E), OSD(PA&E) and OSD(I&L)). Each of the services were required to assemble information in a prescribed format addressing:

- Simulator funding overview FY 73-76
- Simulator program overview FY 73-76
- Flight activity summary FY 73-76
- Test and Study Milestones FY 74-76
- Long range planning for expanded simulation

In addition, written response to 16 specific questions dealing with R&D, Procurement, Military Construction, Operations and General was required of the three services.

In 1974, the DOD Study Group on Flight Simulation proposed a planning goal to reduce flying hours by 25% in the next five years. This ambitious goal was proposed to indicate the level of concern over possible future

fuel nonavailability due to either embargo or high cost and that higher service priority should be given to funding simulator programs. The 25% reduction goal was defined without a thorough analysis of the entire situation and was thought to be beyond the current state of the art by the PA&E TACAIR member of the Study Group.

Although the Study Group did not intend the 25% reduction goal to be a directive, it became widely publicized and was referenced in the FY'77 Planning, Programming and Guidance Memorandum from DOD to the Services. As a result the Services began responding in planning documents as though a directive had been issued. For example, the DOD Report on Flight Simulators — February 1976 indicated plans for investing 1.4 billion dollars in new simulator equipment plus 0.4 billion for modifications and spare parts within the five year interval FY'76-FY'81.

By 1976 several of the cognizant Congressional Committees for the DOD had expressed interest in the DOD programs for flight simulation equipment. The Senate Armed Services Committee Authorization Report for Fiscal 1976 expressed concern regarding the potential degradation of the quality of the flying force due to use of simulators as a substitute for flying. The Committee Report states, "The committee wishes to make it clear that it supports the DOD program efforts to achieve a 25% reduction in flying hours and a saving of energy resources with the increased use of simulators and training devices. However, the committee will not tolerate any degradation in the quality of the flying force from the use of these devices as a substitute for flying." The Conference Committee on Appropriations, however, was concerned with assuring that the Department aggressively pursue the integration of flight simulators into the training programs, and with the impact of increased adoption of simulators.

In August 1975, Calspan submitted a proposal to the Office of the Assistant Secretary of Defense Program Analysis and Evaluation proposing a study to assess the role of simulators in military flight training. The resulting contract was initiated in April 1976 and was performed during the period April - September 1976. The data sources used and the results of the assessment are reported in the following sections.

Section III
INFORMATION SOURCES

This assessment of the role of simulators in military flight training was made on the basis of information obtained from a literature survey and a survey of individuals in industry and government agencies who are knowledgable about flight simulators, military tactical flight training and related matters. Additional information was obtained through responses to a letter mailed to eighty companies listed under Flight Simulation Systems in the 1975 "Aviation Week and Space Technology" Marketing Directory Issue. Also, OASD(PA&E) supplied Calspan with documents prepared by the Air Force, Navy and Army for the 1973 crosscut hearings together with documents prepared by the services for the FY 1977 submission for POM 77 Simulator and Training Device Program.

Literature Surveyed: (See Volume II)

Survey of Knowledgeable Individuals in Industry and Government Agencies

A major part of the survey effort consisted of on-site interviews of individuals in government agencies and industrial organizations who are knowledgeable about flight simulators, military tactical training and related matters. With one exception, all of the survey interviews were performed by a team of two from Calspan, usually Mr. C. Chalk and Mr. G. W. Hall, although in some cases Mr. C. Chalk was accompanied by either Mr. R. Harper or Mr. R. Wasserman. The procedure used was for the team to identify themselves and Calspan Corporation; to identify the authority under which the study was being performed, i.e. OASD(P&E); and to explain that the objective of the study was to make an independent assessment of the status of simulators and the role they should play in military tactical flight training. When visiting military organizations it was stated that the study offered an opportunity for the individuals being interviewed to make an "unscrubbed" input to the DOD at the Assistant Secretary of Defense level.

The individuals being interviewed were requested to brief the Calspan interview team about their organization's responsibilities, activities, and experience related to military tactical flight training and/or simulator research, design, development, procurement, specification, test, operation,

maintenance, certification, training and other aspects peculiar to the organization's function. Prior to each visit the Calspan interview team would discuss the area of expertise that the organization being visited was known to have and, during the interview, questions were asked to guide the discussion and to ensure that these areas of interest were being covered by the individuals being interviewed. Because such a variety of organizations were visited, it was not feasible to formulate a standard list of questions. For example, the expertise of the Air Force Fighter Weapons School is quite different from that of a simulator manufacturer. The purpose of the survey interviews was to gather information and experience that may not be documented and to gauge attitudes of the people involved in the training and simulator business.

If simulator equipment was part of an organization's responsibility, the equipment was viewed and if possible demonstrated. In many cases a Calspan engineering pilot, usually Mr. Hall, had a brief opportunity to fly the simulators. In many cases the host made available briefing material, reports or drafts of documents in preparation. In all cases Mr. Chalk took extensive notes to document the discussions and events of the interview.

The transcribed notes and briefing material were grouped under nine headings and bound into four books of from 80 to 130 pages each. The material in these books was studied at length and consulted extensively in formulating and drafting Volume I of the final report.

The methodology used to perform the survey interviews was questioned or criticized by some of the reviewers of the draft version of this report. The criticism indicates that the reviewer may have assumed that the survey was performed as an opinion survey in which experts would be given a standard list of questions and asked to select from a set of answers the one that best matched their opinion. The results of the survey could then be analyzed to obtain a statistical profile of expert opinion on the issues framed in the standard list of questions. This, however, was not the method used by the author in performing the survey interviews. Instead, the survey interviews were used as an information gathering and educational process to prepare the author to formulate an assessment.

Although this methodology may not fit any standard mold for conducting surveys, and is admittedly unsophisticated, it is the method that was used. The author has conscientiously tried to be objective and realistic in formulating this assessment to reflect "the way things were found to be."

26-28 April 1976

AIAA Visual and Motion Simulation Conference, Dayton, Ohio

1 June 1976

Embassy of Israel, Washington, D. C.
Contacted: Col. Uri Yaari, Air Attache

2 June 1976

Headquarters Tactical Air Command, Langley AFB, Va.
Contacted: Col. Greg Butler
Maj. Kirk Ransom
Mr. C. B. Stoddard

3 June 1976

NASA Langley Research Center, Langley, Va.
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Air Force Aeronautical Systems Division, WPAFB, Dayton, Ohio
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10 June 1976

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Capt. Jerry Balven

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Air Force Human Resources Laboratory, WPAFB, Dayton, Ohio
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10 June 1976

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Flight Control Division - Flight Control Development Laboratory
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14 June 1976

58th Fighter Training Wing, Luke AFB, Arizona
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F-4 Squadron 310 -- Instructors School
F-4 Squadron 311 -- Students
F-4 Squadron 550 -- Instructor Pilots and Students

15 June 1976

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F-4, F-15, F-16
Flight Simulator Facility
Contacted: Col. Charley Brown

16 June 1976

Human Resources Laboratory, Williams AFB, Arizona
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Dr. Milton Wood
Mr. Mike Cyrus

17 June 1976

Fighter Weapons Center, Nellis AFB, Nevada
Air Combat Maneuvering Instrument Range
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Capt. Sammy Small
Capt. B. Mass
Maj. Tom Kennedy

18 June 1976

Fighter Weapons School, Nellis AFB, Nevada
Contacted: Col. Larry Kieth
Maj. R. Koehnke
Several Instructor Pilots

21 June 1976

Air Force Test and Evaluation Center, Kirtland AFB, N. M.
Computer Systems Division
Contacted: Col. Green
Lt. Col. Thomas

24 June 1976

Naval Air Systems Command, Washington, D. C.
AIR 5313 Crew Systems Dept.
Contacted: Cdr. Jim Johnson

Air Force Pentagon, Washington, D. C.
Instructional Systems Branch XOOBB
Contacted: Col. R. Ripley
Lt. Col. Walt Black

25 June 1976

Department of Defense Pentagon, Washington, D. C.
Manpower and Reserve Affairs
Contacted: Col. Vern Junkman

28 June 1976

Chief Naval Training, NAS Corpus Christi, Texas

Contacted: Cdr. Bob Leonard

Maj. Jim Nall

A. D. Windsor

Van Arsdol

Cdr. Lane Hubbard

Cdr. Blair

Cdr. Frank Bachman

29 June 1976

Training Wing 2, NAS Kingsville, Texas

Contacted: Commadore Russ

Lt. Rod Donovan

Two Flight Instructors

TA-4 Squadron VT-21, NAS Kingsville, Texas

Contacted: Cdr. Gilkison

Lt. Buschmann

Two Recent Graduates of VT-21

29 June 1976, cont'd

Flight Simulator Facility T-2, TA-4, NAS Kingsville, Texas

Contacted: Cdr. G. Wren

Mr. Dick Brimmage

Mr. John McIntyre

Mr. Dick Dunbar (General Electric)

30 June 1976

LTV-Vought Aircraft, Dallas, Texas

Contacted: Mr. Chuck Meshier

Mr. Bill Hayden

Mr. J. Engle

Mr. D. Wilson

Capt. Sammy Small

Maj. J. P. Roberts — TAC-ACES

Several Students

1 July 1976

American Airlines Academy, Dallas, Texas

Contacted: Dr. R. Huston
Mr. Don McClure
Mr. Benninghoff
Mr. Gerry Wynn

2 July 1976

Redifon Corp., Dallas, Texas

Contacted: Mr. Herb Cooks

8 July 1976

Navy Pentagon, Washington, D. C.

Naval Aviation Training Division

Contacted:	Capt. O. G. Elliott	OP 593
	Capt. P. S. Daly	OP 596
	Capt. H. P. Fillingane	OP 594
	Capt. W. J. Simpson	OP 593C
	Cdr. R. L. Barton	OP 594B

Air Force Pentagon, Washington, D. C.

Deputy Chief Staff R & D

Science and Technology Division

Contacted: Col. Frank Young

9 July 1976

Navy Pentagon, Washington, D. C.

Debrief of Northrop Experiment to Adm. Kirksey

Director of Aviation Training Division OP 59

Contacted: Adm. Kirksey
Capt. O. G. Elliott
Mr. D. Hirsch
Mr. Sample
Several Others

9 July 1976, cont'd

Naval Air Systems Command, Washington, D. C.
Weapons Training Division NAIR 413
Contacted: Mr. Irwin May

Naval Air Systems Command, Washington, D. C.
Technology Administrators
Equipment and Support Administration Human Factors NAIR-340F
Contacted: LCDR. Paul Chatelier

12 July 1976

NAS Miramar, San Diego, California
OIC FASOTRAGRUPAC DET
Training Squadrons
Contacted: LCDR W. Gilchrist
Mr. Vic Breddell
Cdr. P. Barnes, ASW
Cdr. Marr, Fighter
Instructor Pilots and Weapon Systems Officers
F-4, F-14, E-2B

13 July 1976

NAS North Island, San Diego, California
S-3A Simulator
Contacted: Cdr. W. Christenson

NAS North Island
ISD Office
Contacted: Cdr. Norm Lord

13 July 1976

NAS Miramar, San Diego, California
Air Combat Maneuvering Range
Contacted: LCDR S. Amain

13 July 1976, cont'd

NAS Miramar

Navy Fighter Weapons School - Top Gun

Contacted: Marine Capt. Larry Twiddy

15 July 1976

Northrop Corp., Los Angeles, California

Flight Simulator Group

Contacted: Mr. Doug Linder
Mr. Bill Spring
Mr. Bob Wilson

16 July 1976

NASA Ames Research Center, Mountain View, California

Contacted: Mr. Tony Cook

AMRDL

Contacted: Mr. Dave Key

21 July 1976

Goodyear Aerospace, Akron, Ohio

Contacted: Mr. Brad Peters
Mr. Don Davidson
Mr. Ted Gorsica

22 July 1976

McDonnell Aircraft Corp., St. Louis, Missouri

F-15 Simulation Unit

Contacted: Mr. Harry Passmore
Mr. Dave Harrison

23 July 1976

First International Learning Technology

Congress and Exposition, Washington, D. C.

Technical Session D

Future of Simulators in Skills Development

27 July 1976

Naval Training Equipment Center, Orlando, Florida

Contacted: Mr. Mose Aronson

Mr. Walt Chambers

Cdr. Stevenson

Miss Joanne Puglisi

Army Training Equipment Center, Orlando, Florida

Contacted: Col. Trueman Maynard

28 July 1976

General Electric, Daytona Beach, Florida

Contacted: Mr. Bill Nicholas

Mr. Gene Rowland

Mr. Dallas Butler

29 July 1976

Eglin AFB, Eglin, Florida

TAWC Full Mission Simulator

Contacted: Maj. Bob Macargle

Lt. Col. Dick Lee

30 July 1976

Ft. Rucker, Ft. Rucker, Alabama

Army Undergraduate Flight Training

Contacted: Maj. Walt Bragg

Mr. Ruf

Dr. Bynum

Mr. Bryon

4 August 1976

OSD (P & E) Pentagon, Washington, D. C.

Contacted: Maj. Burkley

5 August 1976

Singer Simulation Products, Binghamton, New York

Contacted: Mr. Gordon Stred

Mr. Dan O'Conner

Mr. Ed Stark

Mr. Vic Faconti

Mr. Dave Cooley

Mr. Wilber Day

SIMULATOR FACILITIES OBSERVED DURING SURVEY

The simulation facilities viewed during this survey are listed below. In some cases, a Calspan Engineering Pilot had an opportunity to pilot the devices and to gain first hand impressions of their operating characteristics. The devices that were flown by Calspan pilots are identified by an asterisk.

NASA Langley

*DMS

6 Post motion base

Model board - TV Camera Visual System

Visual Displays

AFFDL

*LAMARS

Model board - TV Camera

Visual displays

Area of interest

Luke AFB

*F-4 Procedures/Weapons Trainer

*SAAC

F-4 #18

Williams AFB

*ASUPT

*Formation Trainer

Nellis AFB

ACMI

NAS Kingsville

*T-2 2F101

*TA-4 2F90 + 2B35 visual

LTV

A-7 Departure - LAMBS

*ACES ACM

Target image projector

American Airlines

*DC-10 Simulator

Model board TV Camera

Back projected display

Redifon Motion Base

Redifon

Night Visual Caligraphic Display

Video Tape

Aerial Refueling

Carrier Landing and Catapult

Helicopter air-ground with moving targets on terrain board.

NAS Miramar

F-14 2F95 and 15C9

F-4 2F88

E-2B 2F65 and 15F5

Air Combat Maneuvering Range

NAS North Island

S-3 2F-92 and 14B49, 14B50

Northrop

Large Amplitude Beam

Target Projector

NASA Ames

*FSAA

Model boards

Goodyear

F-15

McDonnell

MACS I, II, III, IV

Large Amplitude Beam

Projection Equipment

NTEC

Experimental Equipment

G.E. Daytona

Computer Generated Images

*"Laboratory" Simulator

Radar Simulation

Ft. Rucker

*UH-1 2B24

UH-1 2C35

Night Visual for 2B24

Singer

T-37 and T-38 UPT

AH-1Q 2B-33

CH-47 2B-31

AWAVS

Section IV

ASSESSMENT OF THE ROLE OF SIMULATORS IN MILITARY TACTICAL FLIGHT TRAINING

TIME DEPENDENCE OF ASSESSMENT

This study was performed during the time period April 1976 through September 1976. The documented information available, the equipment observed in field use and the research and development efforts in progress at that time form the basis of the assessment. An increased emphasis has recently been put on research and development of simulator technology and the application of modern simulator equipment to training research. As these efforts come to fruition it will be necessary to re-examine the role that simulators should play in military flight training. An attempt has been made to account for anticipated near-term improvements in simulator technology in the assessment reported in the following sections. This is, however, a difficult thing to do with much confidence for areas that involve new concepts and development of new hardware. Examples were cited during the survey interviews where certain state of the art features had been specified for a new simulator procurement but within the time required to design and construct the device as specified, there were advances in the state of the art which made the use of entirely different hardware feasible and desirable. There are also examples of elaborate and expensive simulator facilities which incorporated hardware that promised to advance the state of the art but fell short of expectations. The result in this situation is an embarrassment to all involved; a specific example is the F-4 #18 device at Luke Air Force Base.

COCKPIT PROCEDURES

There was universal agreement amoung all training organizations and levels within the training organizations interviewed that simple and inexpensive cockpit procedures trainers are highly effective training devices for introducing students to the cockpit environment of a new type aircraft. Specific examples of the use of these devices are the DC-10 device in use at the American Airlines Academy, the F-4 slide-tape device used by the 58th Training at Luke AFB and the UH-1H device 2C35 used at Ft. Rucker.

These devices provide students the opportunity to become familiar with the shape, spatial location and orientation of the various cockpit elements, i.e. controls, switches, instruments, lights, circuit breakers, etc.. They provide students the opportunity to develop proficiency in running through check lists and operational procedures. These devices may simulate the actual equipment only as far as external configuration and will not necessarily respond to trainee control inputs. These devices are considered very important in the total training program of aircrews.

INSTRUMENT FLIGHT

Simulators have been used effectively to train instrument flying procedures for many years, starting with the use of Link Trainers during World War II. Instrument flight simulators have gone through considerable evolution, however, since the World War II Link Trainers were introduced. A typical example of a current instrument flight simulator is the simulator for the T-2 airplane, device 2F 101. The 2F 101 has a replication of the T-2 cockpit with all controls, switches and indicators active; a six degree-of-freedom motion system; digital computer; instructors station with CRT displays; malfunction insertion capability; a control feel system; navigation equipment; record/replay; display of aircraft trajectory at the instructor's console; freeze; initial condition callup; turbulence simulator, buffet simulation; sound cues; GCA simulation; g suit; etc. The 2F 101 is not currently equipped with a visual display and is therefore restricted to instrument flight training and procedures training. Other examples of instrument flight simulators that have recently been put into field service are the TA-4 (2F-90) and UH-1H (2B-24). Flight simulators for the T-37 and T-38 (UPT) were in acceptance testing. These training devices are neatly packaged,easy to operate, have sufficient fidelity to permit instrument training and are exhibiting good reliability and availability. These simulators are excellent supplements to flight training in the respective aircraft. Lacking other constraints, excellent flight training programs could be devised using these training devices together with the airplanes. The pressures to reduce costs and to conserve fuel, however, force those responsible for developing training syllabi to attempt to reduce the flight hours in the aircraft to a minimum and to accomplish training to the desired proficiency mostly in the simulator. The Army reports that the time used to train UH-1 pilots has been

reduced from approximately 50 hours in the helicopter without the 2B-24 simulator to 20 hours in the helicopter plus 25 hours in the 2B-24 simulator. The students are currently being given all the simulator training before they get any instrument training in the helicopter. The Army plans to modify this sequence and mix the simulator and helicopter training. In a training experiment performed by Human Resources Research Organization, a group of 16 students were trained for an average of about 43 hours in the 2B-24 and an average of about four hours in the UH-1 helicopter prior to passing their two-hour and 15 minute instrument check ride in the helicopter. This mix of simulator and helicopter training time has not, however, been adopted in the Initial Entry Rotary Wing Instrument Training Program Syllabus. There was no opportunity to interview students in the UH-1 training program or pilots in combat units to obtain their view of the adequacy, deficiencies or general value of the 2B-24 simulator to the training program.

The cost of operating the 2B-24 simulator is quoted in the April 1976 issue of U.S. Army Aviation Digest and in briefing material supplied by the U.S. Army Aviation Center at $61.24 per cockpit based on full utilization of a 15 hour training day. This is compared to $255.12 per flight hour for the UH-1. The Army claims that the $12.4M cost of five production models of the 2B-24 can be amortized over a period of 1.5 years by reductions in the cost to train pilots for instrument flight. The mix of simulator time and helicopter time used in this calculation was not specified. The calculation is based on 90 per cent utilization of the simulator during a scheduled 10.5 hour training day. The 2B-24 has demonstrated 98% availability for a scheduled 15 hour training day during the period July 1973 through March 1976.

The Navy has procured instrument flight simulators for the T-2 (2F-101) and the TA-4 (2F-90) aircraft. From interviews with individuals in the training system at NAS Corpus Christi and NAS Kingsville, it was learned that the 2F-101 is considered to be a better simulation of the T-2 airplane than the 2F-90 is of the TA-4 airplane. Both simulators are considered to be very useful for training cockpit procedures, emergency procedures, communications, navigation and instrument flight procedures.

When these simulators were first available they were used to train procedures which "really helped to make flight time valuable and helped turn out good pilots." But then a training study was performed and flight time was cut somewhere between 12 and 30 hours. The instructors think they "lost" by participating in the study program. The simulators can be used very well for training in procedures and emergencies but the instructors claimed that the students need the in-flight experience gained by the flights that were cut out. Because of the pressures to reduce training costs and to save fuel they have little hope that the flight hours will be restored once they have been cut. This makes squadron and wing level people reluctant to participate in studies. There was a feeling that the cost/flight hour is the only statistic that the "powers that be" look at and they don't really care about the quality of the graduate.

There was general concern that the flight training programs in the T-2 and TA-4 were at "bone level" and fear that further substitution might lead to accidents. It was recognized that simulators could be used to improve training but also may increase the cost. The goal at the squadron and wing level is to produce an aviator who can fly combat the first time in the fleet, but this tends to get lost in pressure to save money. The fact that a "ratchet" is being used to reduce flight time is a problem to the squadron and wing people. Makes them become dogmatic about not reducing flight time and prevents freely and objectively arrived at balance of simulator and airplane time. This is unfortunate because there does not appear to be any better way to establish this balance than through iteration.

The T-37 and T-38 UPT simulators were not in field use at the time of this review so no feedback on field use was obtained for these simulators.

Individuals in the Air Force 58th Fighter Training Wing at Luke AFB who are active in the F-4 Replacement Training units were interviewed to learn what role the F-4 instrument flight simulator was playing in the F-4 training program. After the student pilots are first exposed to the cockpit procedures trainer to learn basic airplane operation and emergency procedures, they receive three sessions in the instrument simulator before the first flight in the airplane. At this point they can handle the procedures aspects of instrument flight very well but can't fly accurate flight path and are not

prepared for actual IFR flight. The psychological factors are not at play in the simulator, i.e. there is no risk and danger to life. Students may get overwhelmed by these in the actual airplane and forget what they have learned and lose control.

There was mention that the entire F-4 training course previously consisted of 120 hours in the F-4 but as a result of ISD studies the flight hours had recently been reduced to 85-90 hours. This is considered to be at the absolute minimum to send students to operational squadrons and even then the graduates have to spend 25 hours dual before they can fly solo in the squadron. The F-4 simulator is considered to be useful for training procedures, radio operation, fuel management, emergencies, TACAN, navigation, etc. but the simulators are not capable of teaching students to fly or pilot the F-4. The simulator is also used to rehearse a flight mission so that more can be gotten out of the airplane flight, i.e. time management for student and pacing of instruction for the IP students. The simulator is also useful for developing crew coordination between the pilot and weapon systems operator. New students find the simulator experience quite useful for procedures but say it is totally different from flying the airplane. In operational squadrons the simulator is useful for procedures and to develop crew coordination, however, the simulator does not represent the airplane very well and cannot be used to develop proficiency or to learn the limits of the airplane. The requirement for twelve hours every six months in the simulator is viewed by some operational pilots as a waste of time because of the lack of fidelity between the simulator and the airplane.

EMERGENCY PROCEDURES

Another well established use of simulators is for training emergency procedures and abnormal system operation. There are several advantages in favor of performing this type of training in the simulator, the major ones being safety and the fact that some emergencies or abnormal system operations cannot be experienced in the airplane unless the failure actually occurs. Examples are hot starts of jet engines, tail rotor failure on a helicopter, all engines failed on a multi-engine aircraft. These can all be experienced in the simulator provided the effects are well enough known to permit modeling and programming on the simulator computer. Some emergency procedures can be trained in cockpit procedures trainers. Others, which involve instrument indications or control forces, may require an instrument flight simulator. While for some failures, it may be necessary to have visual or motion cues to adequately convey the failure state to the pilot.

If a failure state is to be simulated, it must be analyzed and programmed on the computer or built into the simulator hardware. This requires effort, increases complexity, computer size and cost. Some simulators have been designed to simulate hundreds or even thousands of failure states but when they are put into field use, it is found that only a fraction of those available can be incorporated into the training schedule. During the field interviews there were complaints that sometimes instructors make the students cope with unrealistic numbers and combinations of failures in a single flight. This is, of course, a matter of objectives and judgment. In some simulators the failure states are too rigidly canned and the pilots learn to "outsmart" the simulator, i.e., take corrective action before the emergency has occurred.

During a demonstration of the 2B-24 simulator for the UH-1 helicopter a lateral cyclic hardover was simulated and it was shown that this failure can be recognized and countered if the pilot has been trained to do so. This training is credited with saving a helicopter and six or so occupants.

TAKEOFF AND LANDING

Although instrument flight simulators can be used to train ILS and GCA approach procedures and even to perform blind takeoffs or carrier arrestments, this assessment will address the role of simulators equipped with some form of visual display for these flight phases.

The airline training centers have made extensive use of flight simulators equipped with narrow field of view visual systems for terminal area training. A variety of image generation and image display methods are in use. American Airlines Academy makes extensive use of model terrain boards and servo driven television cameras for image generation and television receivers with collimating optical systems or the Redifon Duoview image display system. American Airlines and Flight Safety International both use the Redifon Novoview night caligraphic computer generated image equipment. Boeing Commercial Aircraft Training Center uses General Electric digital computer generated images, Compu-scenes which are displayed on collimated TV displays.

A number of research simulators located at Government research centers and aircraft companies are equipped with model board-TV camera image generation systems which have been highly developed. The terrain model boards include a variety of terrain and considerable detail such as runway lights, buildings and trees. Some of these facilities have large spherical screens surrounding the cockpit for displaying projected television images.

Several military training flight simulators are equipped with computer generated night caligraphic images displayed on collimated TV receivers. Examples are the F-14 and S-3 operational flight simulators. The Army is experimenting with a night caligraphic display for the UH-1 simulator and is taking delivery of simulators for the AH-1Q and the CH-46 helicopters that will have terrain model boards and TV systems. The AH-1Q pilot will have both forward and 3/4 left vision. To accomplish this, two identical model boards are used with two separate TV camera systems which are synchronized to move over the terrain boards in the proper relative positions and orientations. The

Air Force is taking delivery of simulators for the T-37 and T-38 aircraft that will be equipped with model board-TV systems. The Air Force has two training research simulators that are equipped with visual systems which permit takeoff and landing simulation. These are the ASUPT, which has computer generated imagery and a mosaic of eight special TV tubes with pancake optical windows, and the F-4 #18 which uses a model board and a special wide angle TV probe for image generation and a mosaic of six collimated TV receivers for image display. The Navy has equipped single cockpits of TA-4 (2F-90) simulators located at three bases with visual attachments (2B-35) consisting of digital computer generated images projected by G.E. light valves on to the back of three flat screens set up in front of the cockpit.

This brief review illustrates that a variety of visual image generation and image display methods have been developed and used for terminal area research and training. Some of the facilities described above are prototype developments that resulted in unsatisfactory image displays. For example, the *2B-35 visual attachment* to the TA-4 (2F-90) simulator is not considered to be a useful device for landing training according to Navy instructors and simulator users interviewed. A later generation of the G.E. Compu-Scene computer generated imagery, which is displayed on collimated TV in the simulators used by Boeing to train crews of the 707, 727, 737, and 747 aircraft, is reported to be quite successful and is being used by Boeing in a commercial training service.

The Air Force Flight Dynamics Laboratory has a Redifon terrain model board-TV camera system which is displayed on a Redifon Duoview display in the Multicrew simulator. This visual image generation and display system is one of the best installations of this kind in the country. Reference AFFDL-TR-75-41 reports the results of an experiment to explore the effects of low visibility on landing performance performed by AFFDL personnel using this simulator. The report lists several deficiencies associated with the simulation which are repeated here because similar piloting difficulties have been observed in many other simulators equipped with visual systems and used for landing simulation.

"Although the data package was very extensive and complete and the model responses (frequency and damping) duplicated actual aircraft responses, preliminary test pilots objected to the apparent marginal or neutral stability in roll. Consequently, the aerodynamic derivative C_{ℓ_p} was multiplied by a factor of 2.75 to achieve more roll damping. Typical sink rates at touchdown were 10 ft/sec with little or no flare. The pilots said that their estimates of height and descent rate were inaccurate and they had difficulty in properly flaring the aircraft to avoid hard landings. In general, the simulation was unacceptable in the vicinity of touchdown and the experimental data reduction was terminated at a wheel height of 15 ft. for analysis purposes."

The specific causes of these piloting difficulties are not known nor is it known whether similar piloting difficulties observed in other simulators result from the same or other causes. The problems may be related to delays and lags in the simulator response to pilot commands or a myriad of other reasons. The fix of arbitrarily increasing the roll damping by a large factor appears to be a common practice in the simulator industry. Many examples of tweeking the data or tuning the system to placate pilot objections that "it doesn't fly like the airplane" were encountered in this survey.

The fidelity of the math model used to represent the airplane is put to a severe test when a visual system is included in a simulator. In the survey, several examples were sited of simulators which had previously been used as instrument flight trainers (although not without complaint) but were considered to be <u>un</u>acceptable representations of the airplane after a visual system was incorporated. This is partly because the visual system makes obvious some discrepancies that were not observable before. For example, the visual system makes the behavior of the airplane during ground operations observable and thus requires that the landing gear be accurately modeled. Another reason why simulators become unacceptable after a visual system is added is that with the visual system, the pilot expects to be able to perform maneuvers and tasks requiring a wider dynamic bandwidth. If the simulator has significant lags and delays resulting from hardware and/or computer sampling and computation cycles, then the closed loop pilot-simulator dynamic system may tend to become unstable when the pilot attempts to perform certain tasks. Although this aspect of dynamic behavior is appreciated in the engineering community that uses simulators for

flying qualities research and control system development, it appears that the training community may not appreciate or is only recently discovering the importance of lags and delays to the dynamic fidelity of the simulation. These considerations have implications on acceptable computer iteration rates, the required computer capacity, and the dynamic performance required of motion drive systems, servoed projectors, etc.. The importance of lags and delays will be discussed further in following sections of this report.

As was stated above, several organizations have had the experience that addition of a visual system to a simulator has resulted in the necessity to improve the math model of the airplane. This experience should be generally recognized and its implications to costs of adding visual capability should be recognized. If a visual system is to be included in the simulator, the math model and the data used to represent the aircraft must be of higher fidelity than is necessary for instrument flight simulators. Because of this, extensive testing of the simulator and the airplane may be required to permit identifying sources of discrepancies and to obtain data on which to base computer model changes.

Other limitations to current generation simulators as applied to terminal area training are the narrow field of view which restricts ability to make circling approaches, the small gaming arena that results if the terrain board is scaled to permit low eye height over runway, the difficulty in judging altitude and rate of descent near the runway, lack of scene detail in computer generated images, low resolution of TV images, low image brightness for projected displays. All of these problems are receiving research and development attention and significant technical improvements are expected in the near future.

There are many features of simulators that permit efficient utilization of the student and instructor time and permit concentration on specific elements to be trained. These features are the control of initial conditions and reset, freeze, replay of segments of flight, performance measurement, automation of training sequences and control of environmental conditions such as visibility, wind and turbulence.

An example of the use of initial condition control in the simulator to train students to land was sited by HRL personnel at Williams AFB. They found that an effective training procedure was to initialize the simulator just before flare and have the student complete the landing. Then back up to a point part way down the glide slope and start from there and then repeat again, each time initializing further out. This technique which makes use of unique features of the simulator is reported to be an efficient method for initial training of the landing task.

In summary, simulators are being used to train terminal area procedures and the flying skills associated with ground handling, takeoff, approach, landing, rollout, catapult launch and carrier landing. There are frequently observed lateral control anomalies and landing sink rate performance discrepancies which should be researched and resolved. Visual image generation and display technology is a developing field and improvements in capability and performance are anticipated. Emphasis should be placed on reduction of cost and improved service life. The addition of visual display capability to a simulator places significantly increased demands on the fidelity of the math model and data base used to represent the aircraft and its systems. Because of this, additional effort in testing the aircraft and the simulator should be anticipated.

FORMATION FLIGHT

A capability to fly in close formation is necessary to the performance of military tactical flight operations. Training of this skill involves risk of collision in flight and since the training is performed at an early stage of the student's flight training his general flight experience is not extensive at the time he is exposed to this risk. It is desirable to perform the initial training for formation flying in a ground simulator to minimize risk of accidents and potentially to shorten the flight training program. Formation flight is a visual task and requires a simulator equipped with a wide field of view visual display of the lead aircraft. The visual system must also be capable of generating and displaying the image of the lead aircraft at very short range. The Air Force Human Resources Lab at Williams AFB has developed a relatively inexpensive part task trainer called the Formation Flight Trainer that has been used to explore the feasibility of using a fixed base ground simulator for formation flight training. HRL claims successful use of this trainer to supplement formation flight training in the T-38 aircraft. This simulator was demonstrated to Calspan's engineering pilot during the survey visit to Williams AFB. The Calspan pilot found that it was possible to fly formation and to maneuver about the lead aircraft in a realistic manner. In overtaking the lead aircraft from a distance, it was difficult to judge distance and closure rate and because of this there was a strong tendency to overrun the lead aircraft. For formation flying near the lead aircraft, however, the simulator was adequate to demonstrate the feasibility of using a ground simulator to supplement training for this task. It should be noted that this simulator which cost less than \$300K was judged to be capable of simulation of formation flight but the SAAC and ASUPT machines which cost in excess of \$20M each can not be flown in close formation because pilot-induced oscillations occur when the pilot attempts this task. In the case of the SAAC only loose formation, i.e. separation greater than 100 feet, can be attempted because the image does not change size or perspective at closer range. The cause of this inability to fly formation in these simulators is excessive time delays and lags in the computations and hardware.

To summarize, the feasibility of using a ground simulator with a visual display to supplement formation flight training has been demonstrated. The formation flight task is dynamically demanding and care must be taken to provide the necessary dynamic performance and resolution in the simulator computations and hardware. A wide field of view is required to permit the relative positions and maneuvers typical of close formation flight.

AERIAL REFUELING

Aerial refueling is basically similar to formation flight, however, the field of view required to perform this task is not as extensive as that required for formation flight. This is because the relative positions of the tanker and receiver are more restricted. The dynamic bandwidth and resolution requirements for the two tasks are similar although the magnitude of maneuvers and rates of motion to be simulated can be more demanding in maneuvering formation flight. Several organizations claim development of prototype equipment which permits simulation of aerial refueling. No information is available on training effectiveness of simulators for the aerial refueling task, however, it appears feasible to the authors that refueling training can be effectively supplemented by the use of simulators. Calspan has successfully used the TIFS (Total In-Flight Simulator) airplane to simulate the refueling characteristics of the B-1 airplane. This in-flight simulator was used to train B-1 flight crews prior to attempting refueling in the actual B-1 air vehicle. Consideration should be given to use of in-flight simluators for use as part task trainers for large aircraft such as the B-52 and B-1. The in-flight simulator can be implemented using a smaller aircraft that is much less expensive to acquire and operate than the airplane being simulated. For example, a T-39 or a Learjet could be equipped as an in-flight simulator designed to simulate the refueling characteristics of the B-52 or the B-1 aircraft. This simulator could then be used as a part task trainer to maintain refueling proficiency of SAC operational crews and to expose these crews to actual flight operations.

DYNAMIC FAILURES

Dynamic failures are defined to be failures that result in sudden changes in the balance of forces or moments acting on the aircraft or a sudden change in the operation of a stabilization device. Examples are failures that result in control surface deflections, loss of a control function, thrust loss, damper failure, etc. More specifically engine failure on takeoff, control surface hardover, tail rotor failure, lateral cyclic actuator failure in UH-1 are examples of dynamic failures that result in aircraft motions and/or cockpit control forces and motions that serve to alert the crew to the fact that a failure has occurred and help to identify the specific nature of the failure. Examples were cited in the survey interviews of the importance of force and motion cues in alerting the pilot of dynamic failures.

Examples were also cited of the feasibiltiy of using simulators to train pilots to cope with failures that would almost certainly result in loss of control if encountered by a pilot with no specific training in how to deal with the failure. At Ft. Rucker the effects of loss of lateral cyclic boost and the control technique to be used were demonstrated in the UH-1 simulator. This emergency training is included in the training syllabus and is credited with saving a UH-1 and six lives. It was also reported that an Air Force helicopter simulator with no visual display and limited motion capability was used to simulate tail rotor failure and to train instructor pilots in a recovery technique. It reportedly took 8-10 tries before the IP's learned to recover but a year later 80% were able to recover the simulator on the first try without prewarning that the tail rotor failure was going to be simulated. Northrop cited experience acquired during a program to simulate a STOL transport design which included simulation of engine failure effects. The pilots found the initial motion cue resulting from the engine failure to be critical in alerting them of the failure so they could take recovery action as soon as possible, otherwise they would lose control.

The use of simulators to train flight crews to recognize and cope with dynamic failures has been demonstrated to be feasible. Motion cues have

been shown to be vital aspects of the simulation of many dynamic failures. The use of simulators may be the only feasible way to provide the training experience for failures that cannot be experienced in flight unless the failure actually occurs or for failures that would result in a high risk of loss of control if induced in flight. A significant problem in simulating some dynamic failures may be acquisition of data describing the effects of the failure on the aircraft responses and on the cockpit displays and controls.

TRAINING OF MANEUVER LIMITS

Tactical flight crews must learn to recognize the factors that limit maneuvering performance of their aircraft so that they can fly the aircraft with confidence to the limits of its capability. Training in flight to recognize these limits and to gain experience in flying near them tends to be dangerous and when available flight time is restricted, this type of training will probably be one of the first to be restricted. During the survey interviews examples were cited of operational flight restrictions being imposed that were designed to keep flight crews clear of potential problem situations, i.e. keep speed up and angle of attack low to avoid risk of stall, departure, spin, etc.

It would be highly desirable to have a simulator that could be used to train air crews to recognize cues associated with maneuver limits and one that could be used to practice maneuvering near these limits. A difficulty encountered in mechanizing a specific simulation, however, is the lack of data describing the aircraft characteristics for these situations. The aerodynamic characteristics are likely to be nonlinear functions of several variables such as angle of attack, sideslip, Mach number, configuration, control position, external store loading, power setting, assymetrics, etc. Data to accurately describe these characteristics are extremely difficult to acquire. All the available means, i.e. calculation, model test, or full scale test have limitations on accuracy and the extent that various parameters can be exercised to define the functional interactions.

The pilots who are most in need of training of this type are the pilots in operational squadrons who are trying to get the most capability from

the aircraft they are going to use in combat. Because of this, they demand high fidelity of simulators and if they find that the simulator has characteristics different from the actual aircraft they are likely to reject the simulator on the basis that time spent in it is useful only to learn to fly the simulator and does not improve their ability to fly the airplane.

The F-4 airplane has been analyzed, wind tunnel tested, math modeled, and simulated to a greater extent than most any other airplane in history and yet none of the simulations described in the interviews was considered to have the fidelity at high angle of attack that is required to train operational pilots to recognize and fly with confidence near the maneuver limiting conditions.

The problem of adequately modeling the aircraft and acquiring the necessary data to simulate it to the degree of fidelity necessary to make the simulation useful for training operational pilots is considered to be a major one that will take much effort for each new aircraft and significant model variant that is to be simulated.

There is also uncertainty as to whether or not the motion and force cueing methods used in simulators are adequate to provide the fidelity of cues necessary for the level of training under discussion.

RECOVERY FROM UNCONTROLLED FLIGHT

A number of tactical aircraft (F-7U, F-4 and A-7) have had poor flying qualities and controllability at high angle of attack and large sideslip angles. As a result, these aircraft experience relatively frequent departures from controlled flight and there has been a need to train pilots of these aircraft to recognize situations resulting from loss of control and to train them in the proper control actions to be taken to achieve recovery. In the case of the A-7 aircraft, the Navy has reportedly initiated a training program using the A-7 aircraft while the Air Force has been using the LTV five degree-of-freedom large amplitude beam simulator to train operational A-7 pilots to recognize and recover from loss of control situations. No information was available on the success of either of these training programs in reducing the number of

A-7 aircraft accidents resulting from loss of control and failure to take proper recovery action.

It is believed that simulation to train procedures for recovery from out of control flight is more feasible than simulation to train pilots to fly near maneuver limits. In the latter case fine skills are being developed that depend on accurate simulation of aircraft characteristics. In the case of recovery from out-of-control flight, the task is to recognize the situation and to initiate canned procedures for recovery. Flying skills are not being trained so much as emergency procedures. Because of this, it is thought that less fidelity is required in simulation of the aircraft during out-of-control flight.

Even so, complicated math models of the aircraft and extensive aerodynamic data are required to simulate the various spin modes and responses to control that airplanes can exhibit. Acquisition of the necessary aerodynamic data is regarded as a major problem in this type of simulation.

GROUND ATTACK

A primary role of tactical air forces is to deliver ordnance on ground targets using visual contact and optical sighting devices. Obviously, in order to train for this mission in a simulator, the simulator must have visual image generation and image display capability. The degree to which pilots can be trained for ground attack missions by using a simulator is closely related to the capabilities of the visual system of the simulator. There are many factors which relate to the capabilities of visual systems; some of these are listed below.

- Field of view, both horizontal and vertical
- Resolution
- Image brightness
- Color
- Scene detail
- Size of gaming area
- Ease with which scene or scene detail can be altered
- Feasibility of simulating moving targets
- Feasibility of simulating ground defensive fire
- Feasibility of simulating weapon impact and target damage
- Feasibility of simulating other aircraft in flight

There are many technical approaches and hardware devices being developed to perform the image generation and image display functions; brief descriptions of a number of these are contained in the "Air Force Master Plan — Simulators for Aircrew Training". Depending on the technical approach considered, the factors listed above will interact in various degrees and require different kinds of design tradeoffs to be made.

The visual capability to be required in a simulator used for ground attack training is related to the student's level of proficiency in the task. For example, the 2B-35 visual attachment to the TA-4 simulator presents a very crude cartoon-like picture with little detail and limited field of view. However,

according to instructors at NAS Kingsville, this device has some utility in training novice students to become familiar with bomb range procedures, aircraft switchology and a general appreciation of the visual perspective during a 30 degree dive. The simulator is, however, quite adequate for developing proficiency in delivering bombs on target.

The Air Force has recently performed an experimental evaluation of the suitability of several existing simulators and visual systems for ground attack training. The study is known as project 2235, however, the results of the study were not published at the time Calspan was performing the contract work reported herein. Project 2235 used three simulator facilities with different image generation and image display hardware.

- ASUPT simulator with computer generated images and a mosaic of CRT's viewed through pancake window optical systems.

- SAAC simulator with the F-4 #18 terrain board and wide angle optical probe-TV image generation which was displayed on the SAAC mosaic of CRT's and pancake windows together with computer generated background.

- LAMARS simulator with the AFFDL terrain board-TV camera system used for image generation which was displayed by a projecting TV system on the spherical screen attached to the LAMARS cockpit. This system generates a relatively narrow field of view picture which was presented as a target slaved or head slaved area of interest. A general earth-sky background was also projected on the spherical screen.

The results of the Air Force evaluation of these simulator configurations is not known but one of Calspan's engineering pilots had an opportunity to participate in a study using the LAMARS with the target slaved area of interest display. It was his opinion that this configuration was quite useful for training bombing procedures and skills and for practice of these skills, i.e. training in approach to the target, aircraft configuration management, switchology, control

of aircraft states (speed, dive angle, altitude, bank angle, heading, sideslip, pipper position) at bomb release and scoring of bomb delivery. This visual display would be inadequate if the requirement is to search out targets or to perform a ground attack mission in an area defended by ground fire and air cover.

In the "Air Force Master Plan — Simulators for Aircrew Training", the Tactical Air Command indicates a requirement for a high resolution full field of view visual system capable of presenting a wide variety of ground targets, including moving vehicles, together with airborne friendly and hostile aircraft. A capability to simulate enemy ground defenses, e.g. antiaircraft artillery and surface-to-air missiles, is also included in the TAC requirement. None of the existing simulators has all of these capabilities, however, the ASUPT simulator as configured for the Project 2235 experiments had many of the capabilities at least in cartoon form. The field of view in ASUPT is 280^{o} horizontal and 140^{o} vertical which is quite large. For the Project 2235 study the simulator displayed moving ground targets, ordnance impact, smoke and ground launched missiles. The simulator is also capable of displaying other aircraft, however, it was not programmed to provide imagery of the terrain and the second aircraft simultaneously. All of these images are computer generated and at the current state of development have a cartoon appearance. Various individuals contacted during the survey interviews mentioned the Project 2235 study and reported that the participating pilots were enthusiastic about the ASUPT simulation even though the computer generated images were cartoonish. Calspan had no direct contact with participating pilots, however, and the system was not available for demonstration at the time of Calspan's visit to Williams AFB. The Project 2235 report was in the draft and review cycle at the time of the Calspan study and although a telephone request was made for a copy of the draft, the report was not received or reviewed by Calspan.

The results of a study performed jointly by TAC/AFC to investigate alternatives for training A-10 pilots is reported in a document titled "A-10 Aircrew Training Device Trade Study". This study assumed that a simulator with the capabilities described by the TAC requirements listed above would be available for the A-10 Full Mission Simulator. The study recognized that the combination of a wide field of view and detailed terrain information displayed with high resolution is not currently available in an operational trainer and that only

approximations to this capability have been demonstrated in the research or advanced development devices used in the Project 2235 studies. The Trade Study, however, made the assumption that equipment of the desired capability could be developed. Assumptions were also made about acquisition costs, O & M costs, utilization rates and value of training experience in the simulator relative to training in the aircraft. These assumptions,which form the basis of the Trade Study and are fundamental to the results and conclusions of the study, are examined in the section of this report that is based on the literature survey.

The complexity of the full mission simulator hypothesized in the A-10 Trade Study will probably equal or exceed the complexity of the ASUPT, SAAC or F-4 #18 simulators and like these machines, it will utilize newly developed components because it will be pushing the state of the art in visual system capability. Because of this, we find the numbers used in the trade study for acquisition cost, O & M cost and especially utilization rate to be quite optimistic. This indicates that the projected number of simulators that would be required to handle the training load has been underestimated. Although no hard data are available to the authors on utilization rates of the ASUPT, SAAC or the F-4 #18 there were numerous references during the survey interviews that indicate the operational availability of these machines has been poor, i.e. of the order of 30-40%. The availability of the F-4 #18 and SAAC simulators has been particularly poor. The A-10 trade study assumed O & M costs for the full mission simulator of approximately $100/cockpit-hour compared to $600/cockpit-hour quoted by AFHRL/FT for operation of ASUPT and $250/cockpit-hour quoted by TAC for the TAC ACES air combat simulator. The "Air Force Master Plan – Simulators for Aircrew Training" states that ASUPT utilization requires 26 professional man-years and $1.7M for O & M each year. These numbers indicate a yearly utilization of approximately 1400 hours per cockpit of ASUPT compared to a yearly utilization of 4800 hours assumed for each cockpit of the full mission simulator in the A-10 trade sutdy. A factor of 6 improvement in O & M costs and a factor of 3.4 increase in yearly utilization over ASUPT seems optimistic. These comparisons suggest that the investment costs have been underestimated and the savings rate has been overestimated in the A-10 trade study and therefore the calculated break even points are falacious.

The concept of a trade study is based on the assumption that savings in aircraft procurement and operational costs are possible if a simulator is avail-

able that can be used to replace aircraft training flights at a lower cost and thereby reduce the training costs and the number of aircraft required to handle the training load. Implicit in this concept is some criterion or definition of Mission Ready status, i.e. when do you graduate a student from the RTU training squadron to be a member of an operational unit capable of performing ground attack missions in combat. When a training program for a new aircraft is being established, it is necessary to make estimates of the number of training flights and flight hours that will be required and then when the aircraft becomes available and training experience is gained the training syllabus is revised.

The criterion for Mission Readiness of pilots of current operational aircraft is not very rigorously defined and the number of flight hours in current training programs is a result of other factors, such as cost and fuel consumption, and not just mission readiness. There were many references made during the survey interviews by personnel involved in RTU or RAG training and veterans of operational units which indicate the graduates of RTU training are not qualified to participate in operational missions and must undergo additional training, variously described as: "25 hours dual; 35-40 missions; new guys left home or fly 2 and 4 if emergency deployment required; in Vietnam first four flights made with I.P. in rear seat — in Europe it may take six months to get qualified; real training occurs in operational squadrons — it takes 1-1½ years to bring pilot up to speed; RAG graduates not 100% qualified — they go to beach first and then fly wingman on missions — work into squadron gradually; can only give introduction to air combat in RAG — The operational squadron has to give experience to make a real fighter pilot — Lots of time in squadron is spent practicing for carrier landing qualification". These comments serve to indicate that the criterion for mission readiness is not rigorously defined. Because this is true, it was necessary for the A-10 trade study to set up a "strawman" for training in the aircraft and then to make assumptions about how this "strawman" could be improved upon by the introduction of simulators. If the original assumptions for training in the aircraft are liberal and one makes further assumptions that permit substitution of simulator hours for aircraft hours, then (provided the simulator is cheaper to operate than the airplane) a trade of costs can be calculated. This is what was done in the A-10 trade study. This may not be the only reason to consider

use of simulators, however. For example, if one were to assume that a certain minimum amount of training in the aircraft was required for flight safety and exposure to the flight environment and that this was going to be the maximum amount of flying that would be permitted because of fuel conservation requirements, but that this amount of flying was inadequate to attain mission readiness, then the cost of simulator acquisition and operation would be an added cost that would have to be accepted because of the requirement to save fuel.

To demonstrate how the A-10 trade study results depend on assumptions, consider the effect of assumed aircraft utilization rate on the number of aircraft and simulators required to handle the training load in an RTU wing. Based on the assumed training load and an assumed aircraft utilization rate of 25 hours per month, it would require 150 aircraft to provide the training with no simulators or 101 aircraft if a set of three simulators of varying capability are used. If, however, an aircraft utilization rate of 38 hours per month is assumed, then the entire RTU training load can be accommodated by only 98 aircraft. The Navy claims in data submitted for POM 77 simulator and Training Device Program that the utilization rate experienced in FY 1975 for the T-2 was 41 hours per month and for the TA-4 it was 39 hours per month. Thus, it would appear that the A-10 RTU training load could be handled without simulators by more intensive, but apparently realistic, utilization of only 98 aircraft.

To summarize, ground simulators are currently available, e.g. LAMARS with Target centered area of interest, which can be used to supplement initial training and maintenance of training for air-to-ground weapon delivery. Elaborate simulators to perform the varied functions described in the "Air Force Master Plan - Simulators for Air Crew Training" and the A-10 trade study are beyond the current state of the art and require development of visual simulation technology.

AIR COMBAT

Air combat is the most complex and difficult to train mission that tactical pilots are required to learn. The pilot is required to master complex maneuvers and to use the limits of the maneuvering capability of his aircraft in performing these maneuvers. He is required to observe the hostile aircraft and to make instant evaluations of relative advantage and to make decisions on how to continue the battle or when to disengage. These activities must be performed in an environment of high physical and mental stress. Visual contact with enemy and friendly aircraft is of primary importance in air combat. Because the pilot must fly near maneuver limits while directing his attention outside the cockpit, it is necessary that he learn to use many feel and sound cues in addition to visual instrument readings to evaluate the state of his airplane and whether or not he is exceeding its maneuver limits. The feel cues result from load factor, buffet, flying qualities, control forces, temperature, accelerations in response to thrust changes, etc.

Simulators to be used to train pilots for air combat must have wide field of view visual systems which permit display of aircraft attitude with respect to the earth and display of at least one aircraft in maneuvering flight as it would appear if viewed from the cockpit of the pilot being trained. Simulators with these fundamental capabilities can be used to familiarize pilots with the basic maneuvers used in one-on-one air combat. There are a number of factors important to visual simulation in air combat. The primary requirement is for presentation of the target aircraft in correct aspect, size and resolution at all ranges with range effect on clarity of the image duplicated. For realism and training utility, the simulator should be capable of displaying the sun, clouds, varied atmospheric conditions and lighting effects such as shadows and glint from reflecting surfaces or after-burner light. The display of ground detail should be adequate to convey a sense of altitude and at low altitudes a sense of speed over the ground. To permit training beyond basic air combat maneuvers it is necessary to be able to display images of several aircraft to represent friendly flight elements and multiple enemy aircraft. Simulation of gunsights, weapon launch displays and the trajectory of missiles can be an additional requirement for visual simulation.

The degree to which the many factors listed above must be included in a simulator depends on the level of training that is being attempted. For introduction of novice pilots to the fundamentals of air combat maneuvering the visual system need only include the fundamental capabilities indicated above but for training in planning and rehearsing tactical engagements it is desirable to be able to simulate all of the aspects of the visual world mentioned above.

The fidelity with which the flight characteristics and feel characteristics of a specific aircraft must be simulated is also dependent on the training level being attempted. For introduction of novice pilots to the fundamentals of air combat maneuvering, a generic simulation of an airplane is adequate, however, to develop and maintain proficiency in a specific type and model of aircraft, it is necessary to have a high fidelity simulation of that airplane's characteristics to permit learning the performance capability and flying qualities of the airplane and how to recognize when the maneuver limits are being encountered. Care must be taken to prevent teaching false techniques and false cues that are not applicable to specific aircraft or the actual air combat situation.

Air combat involves maneuvering at high load factor and the effect of load factor on the pilot's body is an environmental effect that can not be duplicated in fixed base or limited motion simulators. Because of this inherent shortcoming it is doubtful that simulators will ever be capable of providing complete substitution for actual air combat experience. A variety of methods and devices are being used to provide the simulator pilot with cues that can serve as substitutes for the effects of load factor on his body. Platform motion, G seats and G suits are the devices most commonly used to simulate or substitute for the motion and force cues of maneuvering flight.

A number of air combat simulators have been constructed by government research agencies, aircraft manufacturers and the training simulator industry. During the survey interview trips, Calspan visited several of these facilities for the purpose of seeing the equipment and discussing the capabilities, applications and experience in using the simulators for air combat simulation. The following facilities were visited:

DMS at NASA Langley
LAS/WAVS at Northrop Corp.

TAC ACES at Vought Corp.

MACS I, II, III, IV at McDonnell Aircraft Corp.

SAAC at Luke AFB

ASUPT at Williams AFB

The first four simulators display the visual scene by projecting images on large spherical domes. The last two use mosaics of CRT tubes with in-line optical systems for collimating the images at infinity. The image of the opposing aircraft is generated by a TV camera viewing a three dimensional servo driven model in all but two cases. The two exceptions, TAC ACES and ASUPT, use computer generated images. All of the simulators have dual cockpits except the Northrop LAS/WAVS. This simulator uses either a computer controlled target aircraft or an instructor flies the target from a special console. The DMS, TAC ACES and MACS simulators are fixed base. All the simulators use G suits and all but the Northrop LAS/WAVS have G seats or inflatable cushions of various designs. Only the MACS III and IV simulators have a capability for displaying more than one aircraft image.

The major use of the DMS simulator has been in evaluating fighter performance parameter variations such as lift, drag, thrust, turning capability and acceleration capability. The project,which has been ongoing for a couple of years, used TAC and Navy line pilots as subjects but since the objective was to study airplane performance parameters, the experiments were designed to average out individual pilot effects. No attempt has been made to follow up with these pilots, after they returned to their duty squadrons, to determine whether or not the four or so weeks of experience flying the DMS was beneficial to them in actual flight operations. One Navy pilot reportedly credited his experience fighting one of the Mig models in the DMS with helping him win an engagement in Vietnam. An Air Force pilot at the AF Fighter Weapons School who had participated in the DMS program and helped set up and run the TAC ACES project at LTV commented that "simulators are wizz-bang for a day or so but then you see the deficiencies One of the major short-comings is in target definition. Pilots can't tell what's going on at a distance, can't see initial move situation well enough." Instructor pilots at NAS Miramar claim the reaction of Navy pilots who have participated in the DMS Project has been varied, some claim it was of no good to them, while another pilot felt he was twice as good after 75 hours in the DMS.

The Northrop LAS/WAVS simulator has been used extensively by Northrop for aircraft design support in the areas of flying qualities and flight control development. The simulator was recently configured for air combat training research and was used to perform an experiment on training transfer and development of automated performance measures. Reports have been written on the results of this program but Calspan did not receive copies during the performance period of this contract. Northrop representatives presented a paper at the AIAA 1976 Visual and Motion Simulation Conference and presented a project debriefing to the Director of Naval Aviation Training in the Pentagon. Calspan attended both of these presentations and interviewed operational personnel at NAS Miramar who had some knowledge of the Navy participation in the experiment. The general impression obtained was that the simulator appeared to have value for the things taught, however, the syllabus was restricted and the experiment design and extent would not permit conclusions. The experiment sample was small and the flights were run in varied circumstances. The experiment group got a good impression of the sight picture at Perch, High Yo-Yo, Low Reversal Point, etc. and learned canned maneuvers, but these are an infinitesimal part of ACM. In practice kills are usually by the wingman after the flight leader has maneuvered the boggie. The experience in the simulator could not be extended to complex ACM, in multiplane maneuvers and multiple aircraft engagements. The experiment developed standardized parameters for the canned maneuvers which have been useful for instructors and have been included in the Navy instruction program for F-4 aircraft. The instructors are better able to communicate with and grade students as a result. After eight tactics hops, the advantage of the simulator experience had been lost. There are 18 hops total in F-4 RAG program. The experiment showed that participation in the simulation program was an aid to the student but it did not show one way or the other whether flight time could be reduced. Followup interviews by the Director of Tactical Air Training Branch could not get any of the Navy students or instructors who participated in the program to state that flights should be eliminated as a result of participation in the simulator program.

The TAC ACES simulator is being used by the Tactical Air Command to explore the use of a fixed-base visual flight simulator as a training device to improve combat skills. The program is described in a paper presented at the 1976 AIAA Visual and Motion Simulation Conference. (Air Combat Maneuvering Training in a Simulator by C. W. Meshier and Maj. J. P. Roberts). The project is also described in an interim report published by the USAF Tactical Fighter Weapons Center "TAC Project - TAC ACES I, Special Project to Develop and Evaluate

A Simulator Air Combat Training Program", April 1976.

The program uses the Vought Corporation's Simulator facility but the training syllabus was designed by the Air Force Fighter Weapons Center and the training program is being executed under the supervision of the Fighter Weapons Center. The students are drawn from Air Force F-4 Operational Squadrons or RTU graduates and by summer of 1976, 44 classes of 8 students had participated in the training program. The interim report by the Fighter Weapons Center presents a fairly critical review of the simulators advantages and the disadvantages which limited the training utility of the simulator. The report contains student comments about TAC ACES program and the simulator facility. In addition, trip reports by several evaluators from other Air Force groups are included. The major criticisms of the simulator were directed at inability to recognize aspect and range because of poor visual image fidelity, poor fidelity of aircraft simulation, inadequate weapons scoring, poor altitude and load factor cues. Without close supervision by highly qualified instructor pilots, these shortcomings could lead to the development of undesirable habits and negative training. Under closely controlled conditions beneficial training has been conducted in the following areas: basic fighter maneuvering, switchology, weapons employment techniques, and high deflection cannon attacks. Calspan visited the Tactical Fighter Weapons Center to discuss the TAC ACES program with the group responsible for conducting the program. A visit was also made to Vought Corp. to witness the simulator training program in operation. In addition discussions were held with officers at the AF Fighter Weapons School who had knowledge of the program and experience with the performance of TAC ACES graduates who entered the Fighter Weapons School as students. There was repeated expression of the opinion that much of the benefit of the TAC ACES program came from the fact that students were free of all other duties for the week spent at Vought and could spend the entire week thinking and discussing ACM. Much of the time spent in the simulator is used learning to fly the simulator. The simulator was considered to have value to supplement flight training but should not replace any flight time. It was good to train habit patterns, switchology but it does not have cues of real situations and can cause pilots to learn to fly the simulator and not have capability in the real airplane. It can also cause bad habits, for example, the target is too easy to find and this encourages pilots to take their eyes off the target. Also, it was reported that pilots have over g'd airplanes after returning to their

squadrons and it is possible they may have learned bad habits or poor techniques from the TAC ACES simulator. Graduates of the TAC ACES program who entered the Fighter Weapons School had better switchology and a little better grasp of concepts but they did not stand out from other students.

Because of flight hour restrictions on operational squadrons the pilots get a minimum of flight time which is devoted to the simplier flying like takeoff and landing. They don't get enough ACM and Tactics training to maintain operational readiness, 16 engagements in 6 months time is typical. In the simulator each pilot gets about 130 engagement attempts in one week. Pilot acceptance of air combat simulation would be high if the fidelity of the simulator was better than the TAC ACES facility and if it was not used to replace flight time or to grade performance. There was general agreement that the simulator should be used to supplement sorties and not to replace sorties now available.

In 1973 there was a move in TAC to retire older pilots and to bring in younger men. Now most squadrons are peopled by young crews with no combat experience and many operational squadrons have pilots with less than 800 hours flying time. Commanders are concerned with safety. Maintaining operational readiness with a numerically inferior force of young low time pilots under the restriction of low available flight time is a problem. There is hope that effective flight simulators will be developed that can be used to supplement the flight training.

McDonnell Aircraft Corp. at St. Louis has four fixed base simulators with spherical domes. MACS I and II have 20 ft. diameter domes and MACS III and IV have 40 ft. diameter domes. MACS I and II have been in service for several years and have been used to support company aircraft developments. At the time of Calspan's visit to McDonnell the MACS III was being used on a contract to provide training for F-15 operational crews because the F-15 operational flight trainer being developed by Goodyear Aerospace had not been delivered. The MACS IV simulator was in the process of being configured for use in support of high acceleration cockpit development at the time Calspan visited the company. Unfortunately, there was no opportunity for the Calspan engineering pilot to fly any of these flight simulators and there was no opportunity to interview any pilots who had experience in the simulators. (It should be noted that although McDonnell has extensive ground simulation capability, including a 5 degree of freedom motion base simulator of the moving beam type, the company recently contracted with Calspan to

perform flight tests in the variable stability T-33 aircraft for the purpose of testing various sidestick design configurations to be used in the McDonnell high acceleration cockpit project.)

The capability described by McDonnell as being available in the MACS III and IV simulators is quite impressive. It is claimed that an air combat engagement can be carried from radar detection through identification, medium range missile attack, visual engagement, short range missile attack, air combat maneuvering and cannon fire attack. At the present time this sequence is being done for two on two engagements. When in visual contact, the simulator has capability to display images representing two aircraft. The following capabilities and features included in MACS III and IV are listed by McDonnell.

Capabilities

- Airframe (Aero, Flight Controls, Propulsion)
- Radar (Mode Control, Detection Models, Noise, Filters, Displays)
- Armament Control Systems
- Cockpit Displays (Head-Up Display, Radar Scope, Radar Warning)
- Lead Computing Gunsights
- Missile Steering and Launch Envelopes
- Electronic Warfare and IFF
- Armament Trajectory Models (Guns, Short and Medium Range Missiles)

Visual Cues

Out-of-Cockpit

- 360° Color Sky/Ground Horizon
- 360° View of Opposing Aircraft
- 360° View of Inbound/Outbound Missile Trajectories
- Gunfire From Opponent

In Cockpit

- HUD
- Radar Scope
- Master Caution and Associated Warnings
- Flight Instruments

Fixed Base Simulator Acceleration Cues

- G Meter
- G Suit -- Same as Aircraft
- G Cushion -- Negative G Cue and Buffet Cue
- Grayout/Blackout -- Blackout all Lights and Visual Displays

Sound Cues

<u>Air Vehicle Associated</u>

- Wind over Canopy
- Speed Brake
- Turbine Whine
- After-Burner
- Compressor Stall
- Stall Warning
- Gear Warning

<u>Weapon System Associated</u>

- Missile Launch
- Gunfire
- Aim-9 Tone
- Hit on aircraft

McDonnell claims the two dome MACS III and IV facility meets the Navy specification for the 2E6 Air Combat Simulator. The company submitted a bid to the Navy for the 2E6 competition. They claim that the cost of simulators to the government is driven up by documentation requirements and the MIL Specifications on simulator hardware.

The major Air Force in-house facility for Air Combat training and training research is the simulator for Air-Air Combat (SAAC) located at Luke AFB. This simulator has recently been installed at Luke AFB and has been in Operational Test and Evaluation. It was used in the project 2235 study of visual requirements for ground attack discussed previously. It has also been used in an experimental training program for air-to-air tactics training called TAC ACES II which was patterned after the TAC ACES I project performed at LTV or Vought Corporation. The results of this project are reported in a final report published by the USAF Tactical Fighter Weapons Center in March 1976. The title is "A Continuation Training Program Using the Simulator for Air-to-Air Combat (SAAC)". This report

is organized in a format similar to the TAC ACES I report. The results of the training experiment are similar to the TAC ACES I results. The TAC ACES II program was discontinued because the in-commission rate of the SAAC simulator was too low (36.1%). The TAC ACES II final report concluded that the simulator was a valuable addition to a lecture course but, because of simulator deficiencies, the training value was limited, and unless properly controlled, could lead to bad habits or negative training. The primary deficiencies were: poor fidelity of the image which limited the ability to determine aspect and range estimation; the performance, stability and control parameters did not duplicate the response of the F-4 aircraft; false cues caused by the motion system detracted from training to an extent that use of the motion system was made a pilot option for most of the training program; departure characteristics of the simulator were not like the F-4 aircraft; and many other detail deficiencies.

During the Calspan visit to Luke AFB the Calspan engineering pilot was given a short demonstration of air combat simulation in the SAAC. His impression from this brief exposure is reported in Appendix A of this report. Discussions were also held with officers in the 58th Fighter Training Wing at Luke AFB, the Fighter Weapon School at Nellis AFB and with the officers at the Tactical Fighter Weapons Center who were responsible for conducting the TAC ACES II project. The general opinion of people who have been exposed to the SAAC simulator is that the motion cues as provided by that motion system are poor quality, i.e. not smooth like an airplane and noticeably false in nature. The motion system exaggerated the tendency to incur pilot-induced oscillations in pitch during gun tracking exercises. False cues were apparent in roll and pitch accelerations when approaching the limits of the motion system. Safeguard limits within the system would frequently shut down the motion during agtressive maneuvering. It is unfortunate that this simulator and the ASUPT simulator have been equipped with such poorly performing motion systems because they are given wide attention within the Air Force and the Training community. The experience reported for the Northrop LAS/WAV and the LAMARS simulators is that the motion systems are a positive contribution to the simulation.

It was reported that following a session in the SAAC some pilots suffer disorientation, headache and eye distress. These symptoms occur after the simulator flight not during it. One squadron commander has,reportedly, directed that pilots cannot fly a real airplane within 3 hours following a simulator session.

Basic fighter maneuvers start at 2-3 mile range but in the SAAC and LTV simulators the target aspect cannot be determined beyond 1.5 miles so pilots can't decide initial conditions and initial maneuvers until range has closed. This simulator limitation forces engagements in the simulator to be performed differently from what is done in flight.

There was general appreciation by the officers interviewed of the potential value of good part task simulators for training basic fighter maneuvering, basic gunnery, identification of the heart of missile launch envelope, etc. They also realize, however, that currently available simluators have serious deficiencies Their concern is that simulators of this quality will be forced on them for use as a substitute for flight training. There were repeated statements by individuals interviewed, at all bases in both the Air Force and the Navy and at various levels from instructor pilots through squadron and wing commanders up to directors of training, that the amount of flight time available is inadequate to train air combat skills and to keep these skills at a sufficiently high level to claim operational readiness.

Although the ASUPT simulator is configured such that it could be used for Air Combat simulation and training it has not yet been used in any air combat training experiments. Experience has been gained, however, in using the simulator for formation flying evaluations. A paper presented at the 1976 AIAA Visual and Motion Conference by Don Gum and W. Albery of AFHRL titled "Integration of an Advanced CIG Visual and Simulator System" describes the difficulty pilots had in flying formation in ASUPT and traces the cause of the problem to "transport" type time delay that is introduced by the motion system hardware and the low iteration rates of the digital computer used to create the computer drawn visual images and to calculate the motion system drive commands. Delays in the visual system of 126-193 ms were being encountered and from 267-400 ms was being encountered in the motion system. This article states that both the motion and visual system lags in the SAAC were about the same as the motion lag of ASUPT, i.e. 267-400 ms. These delays result from sampling intervals, computation intervals and hardware delay. In the ASUPT and SAAC designs there was a lack of appreciation of the importance of time delays and cue correlation to the closed loop dynamics of the pilot-simulator combination when wide bandwidth dynamic tasks are to be performed. This lack of

appreciation for the sensitivity of the dynamic system to time delays led the designers of ASUPT and SAAC to accept hardware of inadequate dynamic response and to use low computer iteration rates for solving the aircraft dynamic equations, space velocity and position equations, the motion system commands, and the visual image position displayed. The net result is that the simulator is "bandwidth" limited when the pilot attempts tasks such as formation flight, tight tracking of target aircraft, etc.. This problem manifests itself as pilot induced oscillation or imprecision in performing tasks which ordinarily can be done in the real airplane.

In survey interviews with technical people who design and operate flight simulators it was determined that the individuals and organizations with experience in flying qualities research and flight control system development were most aware of the importance of time delays whereas the training community was less aware. The upper limit of time delay that can be tolerated is dependent on airplane dynamics and task but about 150 ms is generally considered to be an upper limit. In flying qualities studies it has been found necessary to use iteration rates of 40/sec to avoid noticeable contamination of the pilot's evaluations resulting from time delay introduced by the "real time" digital computer processing and hardware delays. It is believed that the ASUPT and SAAC simulators will be limited in their fidelity for dynamic simulation unless the excessive time delays are reduced.

Calspan has performed a number of flying qualities experiments (under sponsorship of AF Flight Dynamics Laboratory) in the T-33 Variable Stability airplane in which time delay and time lag was introduced between the pilot's control stick commands and the control surface response. This has the effect of delaying the aircraft response to pilot commands in a manner similar to the delay caused by the digital computers and visual or motion system hardware in simulators. The in-flight experiments demonstrate the importance of time delay to flying qualities and the stability of the pilot-airplane combination and to some extent permit quantifying limiting values of time delay as a function of aircraft and control system dynamics and flight control task.

NONPILOT CREW STATIONS

The survey interviews conducted under this contract included discussions with operators, instructors and students using simulators to train nonpilot crew members of the S-3, E-2B, F-14 and F-4 aircraft. These crew members operate sensor systems, radar, weapon systems, communications equipment, etc. It was claimed that nearly all the training for the S-3 and E-2B crew stations could be accomplished in the simulators but the crew member's proficiency in the airplane would be low and therefore it is better to mix the simulator and airplane training. They develop operators to a high level in the simulator so time in the airplane can be used to maximum value.

There are many advantages cited in favor of the simulator for training of S-3 and E-2B crew members. These stem primarily from the ability to control the simulator environment and thus make the time in the simulator a productive training experience. Time wasted by scheduling problems encountered in live training with other aircraft and actual submarines can be eliminated. For example, simulated submarines of various types and various water conditions can be made available on demand for S-3 crew training.

The simulators in use for training nonpilot crew members of the S-3 and E-2B are not without faults, however. There were criticisms of the lack of fidelity or realism in radar simulation, the inability to simulate infrared sensors and lack of capability to simulate radar landmass accurately. In general, the simulators for the F-4 weapon systems operator were considered to be useful training devices although there was again criticism of the fidelity or realism of the radar simulation and the inability to simulate atmospheric effects on the radar display. There was more criticism of the F-14 simulator for the weapon systems operator. This device was criticised as being poorly designed and not adequate to be used for the entire training syllabus. These criticisms were also directed at the lack of fidelity in simulation of radar characteristics.

The use of simulators for training nonpilot crew members is analogous to the use of a flight simulator to train instrument flight procedures. It has been established through experiment and experience that this kind of training can to a large extent be performed in the simulator; however, because of lack of fidelity and realism in the simulator and because the hazard environment of flight cannot be created in the simulator, it has been found desirable to use a mix of simulator and aircraft training to develop the proficiency and competence required for entry into operational units.

Section V

DISCUSSION OF RELATED SUBJECTS

FULL MISSION AND/OR PART TASK SIMULATORS

During the survey interviews it was found that different groups had different ideas about the degree of complexity a simulator should possess and what combination of simulators should be used in a training program. The terms Full Mission Simulator and Part Task Simulator have been used to describe two degrees of complexity. The term Full Mission Simulator implies a capability to perform a complete mission from cockpit entry to cockpit exit including capability to interact with the environment, enemy defenses and other aircraft in a war game context. The term Part Task Simulator implies a simulator designed to perform a specific task such as refueling or formation flying or air combat or ground attack, etc.. Since the Full Mission Simulator can do everything there are advocates who suggest only buying that kind of a machine and to use it to perform the training of mission subphases. The arguments against this approach are that use of a Full Mission Simulator for training subphases is wasteful of the resource, that Full Mission Simulators are extremely expensive and complex and therefore will have low in-commission rates. Also, the training load may exceed the training capacity of a limited number of Full Mission Simulators. The arguments for Part Task Simulators are that these simulators can be designed specifically for each part task and need not be compromised by conflicting requirements of other flight tasks; the Part Task Simulator should be simpler and less expensive to acquire and operate and therefore more copies can be acquired and deployed in the field. Concern was expressed that if the training requirements specify a capability for Full Mission Simulation, then it may be hard to justify part task simulators in addition.

Theoretically, if the ISD (Instructional System Development) method is used to design a training program, the media selection phase will define the most cost effective combination of training devices to accomplish the required training. The training program and the training devices selected will be a

function of the "command" direction which must specify what degree of proficiency graduates of RTU courses must attain and what level of combat readiness operational squadrons are expected to maintain. The training program and the training devices selected will also be a function of constraint factors as well as desired proficiency levels. Examples of constraints are cost, fuel conservation, airframe life extension, air space restrictions, geographical deployment of training units and operational units.

It is noted that advocates of Full Mission Simulators make the assumption that the Full Mission Simulator will be capable of simulating all of the subphases that might be considered for Part Task Simulation. This assumption may turn out to be false if design requiements for the subphases are not thoroughly appreciated. For example, in the design of the ASUPT an apparent lack of appreciation of the importance of time delay caused design tradeoffs in computer size and iteration rate (which were brought about by the desire to build a simulator that could do lots of things, i.e. a "Full Mission" Simulator) which in the end produced a simulator that was not suitable for formation flight training. As one Air Force officer we interviewed observed, "The Air Force tends to seek the ultimate and often ends up with nothing."

SUPPLEMENT OR SUBSTITUTE

The Office of Management and Budget, the General Accounting Office, the Conference Committee on Appropriations and the Federal Energy Agency all advocate increased use of simulators to reduce training costs and to conserve fuel. These savings can only be realized if simulator time is substituted for flight time.

The Air Force and Navy tactical training officers contacted during the survey interviews unanimously stated that the flying time allotted for advanced tactical training and tactical operations has been reduced to a level that does not permit maintaining adequate operational readiness and that if funds are to be invested in simulators for tactical aircraft, the justification must be to improve the operational readiness by supplementing the current flight training. This may increase training costs for tactical forces and will not result in significant fuel savings. Implicit in this stance is the belief that simulators are not available, nor will they be in the near future, which can be used to substitute for the current flight hours devoted to tactical training.

One officer observed that the question of supplement or substitute becomes moot for new aircraft because training programs will be designed by the ISD process and will include the proper mix of training performed in the aircraft and in simulators. This point of view places much faith in the ISD process and assumes that careful, evaluative iterations will be performed over the total service life of the instructional system (validation phase) and that the mix of simulator training and in-flight training will be adjusted as necessary. In the initial design of a training program by the ISD process, one eventually arrives at the point where judgments must be made as to which tasks can be trained in simulators and which tasks must be trained in the aircraft. This decision must be based on a realistic appraisal of the training potential of the simulator being considered for training a particular task. Because training programs developed by the ISD procedure involve judgments of the value of training performed in simulators relative to that performed in the aircraft, there is no way to be sure the proper mix of training will be pro-

posed. Current emphasis on reducing cost and fuel consumption and the advocacy for using simulators may bias the judgment of how much training can be performed in simulators. Because of this possibility it is recommended that those responsible for flight safety and operational readiness of new aircraft be alert to the possible need to iterate the distribution of training between simulators and the aircraft.

Concern was expressed that acts of Congress that effect development of fuel sources and the decontrol of naptha may have a gross effect on the availability and cost of aviation fuel and that such events would have a tremendous impact on the use of simulators. The implications of such events are beyond the scope of this study. We can observe that changes in the availability and cost of fuel will have a significant effect on all aspects of life. There may be effects on alliances of nations which may require the United States to increase its military preparedness and Congress may have to recognize this need and arrange priorities and funds accordingly. In cases where simulators are capable of providing training they will no doubt be put to greater use because of the increased cost advantage; however, we repeatedly encountered instances in which the training people claimed current simulators were of limited capability and that training in them beyond a certain point would not be of further benefit to performance in the aircraft. In these cases it will be necessary to continue training in the aircraft and attempt to correct the deficiencies in the simulators that limit their training usefulness.

ALTERNATIVES TO SIMULATORS

During the survey interviews the point of view was expressed that because aircraft must be in the inventory and will have a limited life because of technological progress, then the maximum use should be made of the aircraft during their serviceable life. It was recommended that effort be directed at development of onboard instrumentation and recording to permit measurement of aircraft parameters and weapon release parameters to facilitate debriefing and to aid in training. Instrumented aircraft and instrumented ranges such as the Air Combat Maneuvering Range are advocated to permit more efficient training in the realistic environment of flight in the actual aircraft. Development of ways to simulate and score ordinance delivery are advocated to reduce training costs due to consumption of ordinance. Development of methods and equipment for stimulating the airplane sensors by computer has been advocated as a way to use the aircraft on the ground as a simulator for training crews. This approach has particular application to missions such as anti-submarine warfare, early warning and weapon systems using sensor information and displays.

THE AIRLINE TRAINING EXAMPLE

The training programs of major airline companies have been cited by the USAF Scientific Advisory Board, the Office of Management and Budget and the Comptroller General as examples of the use of ground simulators to reduce flight hours in training programs. In order to learn about this example, the authors chose American Airlines as a case in point and spent a day at the American Airlines Flight Academy interviewing personnel responsible for their training program and the simulation equipment. Reference was also made to the description of the training program contained in the AIAA paper No. 75-1049 presented at the AIAA 1975 Aircraft Systems and Technology Meeting.

Prior to 1967, a Captain transitioning into a 727 type aircraft was given approximately 21 hours in a 727 aircraft dedicated to the training function. At the present time, Captains are "transitioned" into the 727 aircraft with only 1.0 hours in the actual aircraft. See Figure 5 taken from Ref. 1. These check flights are performed in service aircraft between revenue flights and it is no longer necessary to devote aircraft solely to the training function.

This major revision of the training program resulted from application of the Systems Approach to Training or the Instructional System Development (ISD) Method and the introduction of the Operational Flight Trainer and other training aids such as the Cockpit Procedures Trainer, airplane systems trainers and learning carrels. American Airlines claims the revised training program reduces their total training cost by $8M and saves 30M gallons of fuel each year. (United claims $13.4M and 54M gallons of fuel saved each year.) In addition, they have reduced the risk of flight accidents during training of emergency procedures by performing the majority of this training in the ground simulator. Actually, training for some failures and emergency actions is given only in the ground simulator.

The economies achieved by American Airlines through revision of their flight training program and the introduction of ground simulators are impressive, however, it is necessary to examine this training situation in more detail and to compare it with the Military training situation before drawing any conclusions about potential savings in the Military training program that

might be realized by a similar use of ground simulators.

The example discussed above, and the graph from Figure 5 of Reference 1, is for an airline Captain transitioning into a new aircraft type but in the same crew position. Because of union seniority rules and crew bidding procedures, it is most likely that an established Captain will have several thousand hours of flying experience at the time he enters transition training for a new aircraft type. In the Navy a student pilot may enter the F-4 RAG with 250 hours total flight experience.

The Airline Captain transitioning to the 727 aircraft receives approximately nine days of training in programmed instruction using slide/tape, Video, aircraft systems trainers and cockpit procedures trainers. Approximately half of this time or 36 hours is spent in the cockpit procedures trainer. The pilot then gets about 32-36 hours in the flight simulator divided about equally between time at the controls and time as an observer. The Flight Superintendent who conducts the final phases of simulator training and rating also conducts the non-passenger carrying check flight in the 727 aircraft. At this point, the Airline states that the Captain is fully proficient in all phases of the operation of the aircraft. This statement, together with the graph of Figure 5, leads one to conclude that the Captain has "transitioned" into the new airplane with only one hour in the actual aircraft. In reality the Captain's training extends beyond this point to what American Airlines calls "line experience." During "line experience" the Captain is under the direct supervision of the Flight Superintendent who flies as copilot for the first few passenger carrying flights and as an observer and coach for a total of 25 hours. Thus the Captain receives an additional 25 hours of "training" or supervised experience in the aircraft beyond what is shown on the graph of Figure 5. It should also be noted that the Captain will have a copilot and flight engineer in his 727 crew who will probably have several hundred or even thousands of hours experience in the 727 aircraft.

Because the military missions of MATS and to some extent of SAC are similar to the airline missions, the airline training methods and use of ground simulators may well serve as an example for reviewing and revising the training of MAT and SAC aircrews.

The mission for which the airline pilot has been trained is relatively

simple, however, when compared to the many tactical missions of the F-4, for example.

The USAF Operational Training Course for the F-4 airplane, Course No. 111507B, is outlined in Attachment 1. This syllabus was being used in about 1973 and has been revised to reduce the flight hours to 92 since that time. Graduates of this course were considered mission capable in the F-4 aircraft for complex missions such as air combat and ground attack in day, night or radar conditions. The F-4 course calls for:

Academic Instruction 231 hours + 115 hours study.
Simulation Training (18 + 33) = 51 hours
Plus 22 hours Brief and Debrief.
Aircraft Flying — 100 hours.

The majority of this training deals with the weapons systems and the special maneuvers associated with air combat and ground attack flying. The portion of the training directed at "transitioning" into the F-4, i.e. learning the basic airplane systems and learning to fly the airplane well enough to permit cross country operations under instrument conditions is estimated as follows:

Academic Instruction 70 hours + 35 hours study.
Simulation Training (18 + 12) = 30 hours
Plus 7 hours Brief and Debrief.
Aircraft flying — 23 hours.

In comparison, the Captain transitioning into the 727 aircraft receives approximately:

Carrels, Systems Trainers, FS observation $\simeq$ 55 hours.
Simulation Training $\sim$ CPT + FS = 36 + 20 $\simeq$ 56 hours.
Aircraft flying $\sim$ Check flight + line experience $\simeq$ 5-10 hours with Flight Superintendent flying as copilot.
$\sim$ Plus 15-20 hours supervised flying with an experienced crew.

Although some of the adjustments to the hours spent in different phases were not based on precise knowledge, it is believed that they are roughly correct. This comparison of the airline Captain transition program and the Air Force RTU program to transition a student into an F-4, to the extent that he could fly an airline type mission, shows more similarity than a superficial comparison of the graph, Figure 5 of AIAA paper 75-1049, and the tables in Course No. 1115088, pages 73 and 74, would indicate. It should also be noted that the airline flight simulators are equipped with visual displays that permit training for takeoff and landing whereas the F-4 simulator is an instruments only device.

Examination of the F-4 syllabus shows that 69 of the 100 flight hours and roughly 20 of the 33 flight simulator hours are devoted to training for the Tactical aspects of the F-4 mission, i.e. air combat, ground attack, formation, aerial refueling, etc.. Although the goal of Operational Training Course 11507B is to produce a mission capable aircraft Commander, it was the opinion of various instructor pilots, operations officers and veterans of operational squadrons that the RTU graduate is not prepared to go into combat when he first joins the Operational Squadron. The operational squadrons must provide considerable additional training before the new crew is combat ready. This view was also expressed by Navy officers concerning the adequacy of graduates of the RAG squadrons.

Another aspect of pilot training is maintenance of skills or proficiency training. In this regard the airline and military situation is very different. The airline pilot flies 50-70 hours per month in normal airline operations whereas the operational military pilot may only experience from 10-20 flight hours per month.

American Airlines requires each Captain to complete Recurrent Training twice each year. The purpose of this training is to insure that he retains his proficiency in abnormal and emergency procedures since these are only trained in the ground simulator. The amount of time devoted to this training is not specified in the AIAA paper.

The Military Regulations also require recurrent training in ground simulators. For example, Air Force regulations require 12 hours every six months in the F-4 ground simulator. The Navy has recently revised the "NATOPS General Flight and Operations Instructions" OPNAV Instruction 3710.1H to permit 50% of the required minimum (100) flight hours/year to be logged in an approved ground simulator. This instruction applies to 21 airplane types. Six of the required 12 hours of instrument flight may be logged in a ground simulator. The Army also allows one half of the required IFR helicopter time per year to be logged in approved ground simulators and is requiring that at least 10 hours/ year IFR training be done in the ground simulator.

In summary, the following observations are made in contrasting the American Airlines Transition Training program for airline Captains and the USAF Operational Training Course for the F-4.

1. The experience level of pilots entering the two training programs may be greatly different.
   Airline Captain – Probably several thousand hours.
   F-4 student – As little as 250 hours.

2. The Airline Captain may only receive one training/check flight in the actual aircraft without passengers but his training in the aircraft continues for a total of 25 hours additional hours. This training is performed on passenger carrying flights with a Flight Superintendent flying as copilot for the first few flights and as an observer and coach for the remainder of the 25 hours. During the latter portion of this line experience, the copilot and flight engineer accompanying the new Captain will probably be highly experienced in the airplane type.

3. The airline simulators are equipped with visual displays which permit training for takeoff, landing and ground operations. The lack of this capability in many military airplane simulators such as the F-4 makes it necessary to perform more of the training for these operations in the airplane.

4. The tactical missions of the F-4 require additional training to develop flying skills for formation flying, aerial refueling, air combat and ground attack. Specialized training is required to permit maneuvering with confidence near the flight limits of the aircraft. In the F-4 syllabus, 3/4 of the flight training is directed at these tactical mission-related tasks and skills.

5. The F-4 aircraft are equipped with a number of weapon systems. Nearly 2/3 of the ground training in the F-4 syllabus is associated with the weapon systems characteristics and operational procedures.

6. Airline flight crews regularly fly 50-70 hours each month. Operational pilots in F-4 squadrons may only fly 10-20 hours/month.

7. The Airline training program and the Military training regulations both require use of the ground simulator for recurrency training in instrument procedures and emergency procedures.

When compared on the basis of training for a similar mission, we found that the Airline Captain transition training program and the Military training program for F-4 Aircraft Commanders are more similar than they initially appear. Both programs use the available ground simulator equipment to good advantage.

The majority, about 2/3, of the F-4 Aircraft Commander training is directed at learning the flight skills and the characteristics of the weapons systems associated with the Tactical missions of the F-4 aircraft.

Course No. 111507B

SECTION I

GENERAL INFORMATION

1. Course Title: USAF Operational Training Course, F-4

2. Course Number: 111507B

3. Purpose: To graduate combat mission capable F-4 aircrews.

4. Location: 1 TFW, MacDill AFB, Fla.
31 TFW, Homestead AFB, Fla.
35 TFW, George AFB, Calif.
58 TFW, Luke AFB, Ariz.

5. Duration: 13 ground training days plus 108 flying days.

6. Status Upon Completion: Upon satisfactory completion of this course, Aircraft Commander graduates will be considered mission capable and awarded AFSC 1115F. Weapons Systems Officer (WSO) graduates will be considered mission capable and awarded AFSC 1555C.

PHASES OF TRAINING

Flying	Sorties		Hours	
	AC	WSO	AC	WSO
Transition	12	3	18.0	4.5
Instruments	3	1	5.1	1.7
Formation	5	3	7.5	4.5
Air Combat Fundamentals	8	5	10.7	7.5
Air Combat Maneuvering	5	5	4.0	4.0
Dart	4(2)*	3(1)*	6.0(3.0)*	4.5(1.5)*
Ground Attack	13(12)*	10(9)*	18.2(16.8)*	14.0(12.6)*
Air Refueling	6	3	14.4	7.2
Ground Attack (Tactical)	3	2	3.9	2.6
Ground Attack (Night)	3	2	3.9	2.6
Ground Attack (Radar)	3	4	4.5	6.0
Air Combat Tactics	5	3	4.0	2.4
TOTALS	70(67)*	44(41)*	100.2(95.8)*	61.5(57.1)*

* DENOTES F-4C

Course No. 111507B

SIMULATION TRAINING	HOURS AC	WSO
Simulator	33.0	31.5
Simulator Briefing/Debriefing (1.0 hr/sortie)	22.0	21.0
Cockpit Procedures Trainer	10.0	3.0
Part Task Trainer	2.0	5.0
Egress Trainer	6.0	6.0
TOTAL	73.0	66.5

ACADEMIC TRAINING	AC	WSO
Specialized Training	17	17
Life Support	4	4
Aircraft General	23	14
Instruments	15	15
Formation	4	3
Flight Characteristics	3	3
Radar	8	23
Air Combat Fundamentals	22	22
ACM/Dart/ACT	28	28
RHAW/ECM	11	11
Conventional Weapons	36	36
Nuclear Weapons	14	14
WRCS	12	12
Combat Mission Planning	9	9
Ground Attack Night	4	4
Air Ground Operations	6	6
Intelligence	9	9
New Developments	6	6
Academic Preparation (.5 hr/hr Academic Inst)	115	118
TOTAL	346	354

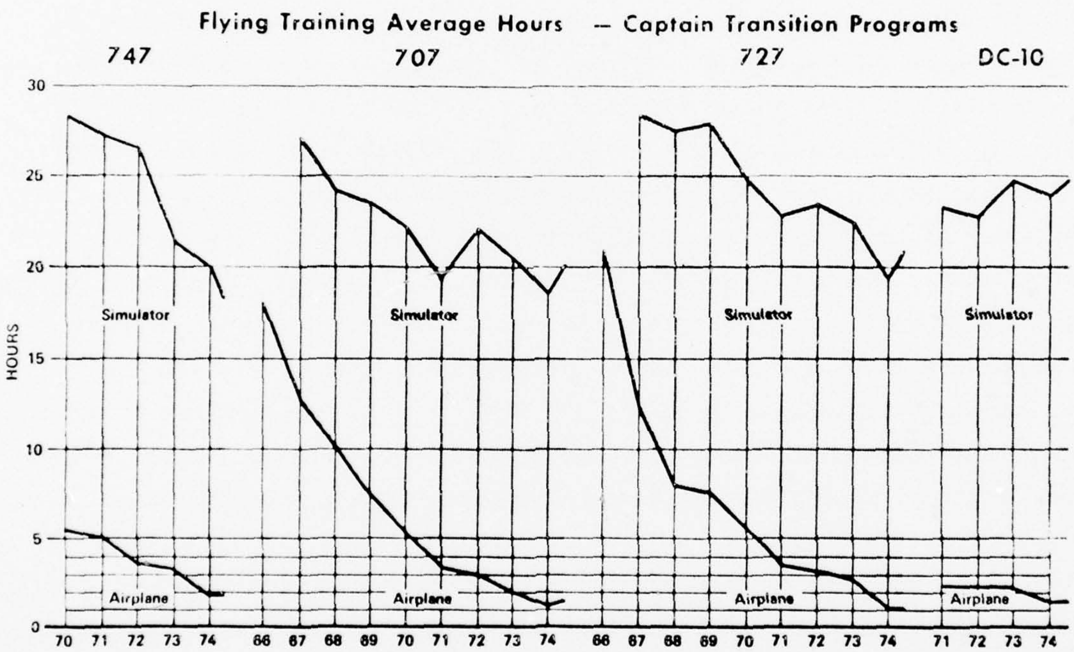


Figure 5 of AIAA paper 75-1049.

Section VI

PROBLEM AREAS REQUIRING RESEARCH AND DEVELOPMENT

FIDELITY OF AIRCRAFT SIMULATION

The factor which limits the training capability of simulators is the fidelity with which they simulate the cues; environment and events that the flight crew will encounter in aircraft operations. The mathematical model of the aircraft that is used to calculate the responses to pilot control inputs and external disturbances is of particular importance to the fidelity of piloted simulators. This model can be quite complex for aircraft with large flight envelopes, many configuration variables, and aeroelastic effects. For tactical aircraft that require maneuvering at high angle of attack the aerodynamic characteristics can be nonlinear functions of several variables. An extensive amount of data is required to accurately model an airplane, in fact more accurate and detailed data is required to simulate an airplane than is required to design and build the airplane. This is not a new discovery, the problem has been around for many years, it's just that the problem is made more difficult by the increase in complexity of airplanes (i.e., variable sweep) and the increase in range of parameters (i.e., dynamic pressure, mach no., angle of attack and side slip) together with the addition of visual systems. The increase in complexity and parameter range requires more data and the addition of visual systems increases the accuracy to which the data must be known. The growth of the aircraft mathematical model together with the increase in other aspects of simulation creates a high computation load. Some designers have resorted to low computer iteration rates as a way to keep the computer size and cost within limits. The addition of visual systems, however, has the effect of making possible simulation of piloting tasks that require higher bandwidth performance from the pilot-aircraft combination and the importance of time delay, introduced by the computer and simulator hardware, can become critical. The net result can be a dynamic simulation that is unacceptable. The point to be made is that a more complex model may lead to a poorer simulation than a less complex model if compromises in computer iteration rate accompany the more complex model.

The fidelity required of the math model increases as the pilot's knowledge of the airplane and level of training increase. Pilots tend to reject simulators that do not represent the airplane. The addition of visual systems permit accomplishing additional tasks and make obvious some things that were not observable without the

visual system. For example modeling of landing gear characteristics or response to brake release, etc.

The problem of generating the required data is considered to be a major one that will be expensive to solve and will be organizationally difficult because the simulator designer must depend on the aircraft designer or a government agency acting as intermediary. Responsibilities can be divided, proprietary interest can be involved and different formats for describing data may be encountered. The Air Force simulator SPO has let a contract to study this problem and to establish data requirements. This contract will, hopefully, better define the data required but the cost of acquiring the data will be a continuing burden.

Another aspect of math model fidelity and digital computers is the potential for inaccurate real time calculation of high frequency dynamic modes such as structural modes, control system dynamics, rotor dynamics, etc., unless high speed computers and high iteration rates and special numerical processes are used.

MOTION AND FORCE CUEING

Motions of the aircraft and forces applied to the pilot's body are important cues to the pilot for alerting him of uncommanded responses, confirming that commanded or expected events have occurred and as a form of feedback during controlled maneuvers. Forces and motions can also create an environment that imposes stress and fatigue on the pilot and interferes with his ability to read instruments, approach plates, etc. The effects of high load factor on the body are an important aspect of air combat.

Various approaches have been taken to simulate the motions and force cues. The highest fidelity is achieved in in-flight simulators such as the AFFDL total in-flight simulator known as TIFS. This airplane has three moment and three force controllers which permit duplicating the motion and force environment of another airplane in flight. In the case of ground simulators, however, it is not possible to duplicate these cues and resort is taken to simulation. The devices used are motion platforms, shakers, inflateable cushions (G seats) and inflateable "pants" (G suits). The G suit is usually an adaption of flight gear, in fact some simulators use the G suit the same way it is used in airplanes, i.e., inflation

does not start until $n > 2.0$ but the pressure increase with G is reduced. It is thought by some that this is the wrong way to use the G suit, they argue that its function is completely different in a ground simulator where it is being used as a substitute cue for G whereas in flight its purpose is to prevent blood pooling and thereby delay backout. Since it is being used to simulate the G cue in a simulator it is argued that the inflation should start at $n = 1$ and not duplicate the operation in the aircraft.

Cockpit shakers are used to simulate buffet of the airframe, i.e., structural vibration excited by turbulent airflow. Extreme buffet may require motion of the platform. In some cases rapid pulsing of the pressure in seat cushions or G seats has been used for buffet simulation. The G seat was first introduced as an attempt to simulate the steady-state effects of load factor, i.e., sinking in the seat and increased pressure on buttocks. More recently, there have been experiments to determine the utility of G seats for simulation of other force cues such as postorial tilt, cueing of engine failure, and to provide continuous feedback in tasks such as tracking. There is hope in some circles that G seats and G suits can be developed to an extent that they will obviate the need for motion platforms. Elimination of motion platforms would simplify simulators, reduce costs and potential maintenance problems and also make the design options for visual systems wider and eliminate the requirement to harden visual system elements because of the acceleration environment. These are attractive reasons for building up a case for eliminating the motion platform and it appears that G seats and G suits may be used as the justification.

Motion platforms of various designs have been used to simulate aircraft motion responses to control inputs, turbulance, airframe buffet, engine or control system failures, store release, runway contact, etc. The degree of realism that can be achieved is a function of the acceleration, velocity and displacement limits of the platform motion system together with the dynamic response and smoothness of operation. In addition, the number of independent degrees of freedom available influences the motion realism that can be obtained. In the world of ground simulators there is a tendency to treat the various degrees of freedom as being independent and in many cases to completely eliminate some of them. In flight the degrees of freedom are interrelated by the equations of motion and the characteristics of the airplane. Because of this, motion in one degree of freedom must be accompanied by motion in the other degrees of freedom. If this does not occur properly, then attempts to generate one cue will be accompanied by other false cues. For example when an

airplane is rolled to a bank angle and is "coordinated" by use of the rudder, it will enter a turn and the pilot will not have any tendency to fall sideways in the seat. If this maneuver is attempted in a ground simulator that has the roll degree of freedom but does not have any lateral translation degree of freedom, the pilot will end up leaning against the side of the cockpit as the airplane banks. Thus an attempt to simulate motion in the roll degree of freedom is accompanied by a false lateral acceleration or force cue. To prevent this it is necessary to accelerate the cockpit laterally as the bank angle is developed (actually it is also necessary to move in other degrees of freedom also). Thus we can conclude that, for the purpose of simulating the motions of an airplane in response to control, the magnitude of motion available in one degree of freedom may be necessary to permit developing a motion cue in another degree of freedom without incurring an overpowering false cue. Because of this, simulators with roll but no sway end up using very small roll motions. The NASA FSAA has large lateral travel and so it is possible to drive the roll degree of freedom more nearly like the airplane without experiencing false lateral acceleration cues. If one watches the FSAA in action, the most noticeable motion is lateral translation but this motion is occurring to prevent false lateral acceleration cues from accompanying roll motions.

There is a debate underway within the Air Force to decide whether or not motion systems are worth the complication and cost they cause. The AFHRL has been performing experiments using the ASUPT simulator to try to answer this question. The approach being taken is to use objective performance measures and statistical analysis and incidentally a simulator with a very poorly performing motion system. The results of these studies are not held in very high regard by people in the engineering and research community (NASA, Redifon, AFFDL and Calspan). During the survey interviews, Calspan asked individuals in the training business who operate and use the simulators whether or not they thought the motion system was of any value. Very positive responses were given by American Airlines, the Army users of the UH-1 (2B24) instrument flight simulator, the Navy users of the S-3 (2F92) operational flight simulator which has VITAL III night visual display, and the Navy users of the F-4 and F-14 operational flight simulator. The F-14 also has a night visual display. They all stated that the motion system adds realism and the students treat the simulator more like it is an airplane. "With motion OFF the S-3 simulator is benign as a wet noodle -

just not satisfying. Motion is essential." "Students tend to horse around without motion, abuse the airplane. Don't use F-4 simulator without motion." "UH-1 motion highly desirable. Adds realism. Strong recommendation it is worthwhile." It is believed that this kind of observation by experienced users of the equipment is valid evidence and supports the case for including motion, at least in instrument and operational flight simulators. In the case of air combat simulation where large field of view visual systems are mandatory, it may be advisable to make design trades between requirements for visual simulation and requirements for motion and force cueing. The NASA DMS, TAC ACES at LTV, and the MACS I, II, III & IV at McDonnell are all fixed base simulators which include G seat, G suit and in some cases cockpit vibrators. There is no doubt that the design of each of these simulators was simplified by elimination of the motion system. Also there is no doubt that these simulators have utility for supplementing air combat training. The SAAC has a wide field of view visual system mounted on a 6 degree of freedom motion base but because of the poor performance of the motion system and the large computer delays in both the motion system commands and the visual system displays, this simulator has less utility for training than some of the simulators without motion. The Navy AWAVS simulator will consist of a wide field of view visual system mounted on a 6 degree of freedom motion base. Design specifications for this simulator indicate major improvements in the performance of both the visual system and the motion system are being attempted relative to previous simulators. The Northrop LAS/WAVS and the AFFDL LAMARS simulators both have large field of view visual systems and 5 degree of freedom motion systems. These three simulators (AWAVS, LAS/WAVS and LAMARS) are potentially the best suited for research on the value of motion to air combat training. Unfortunately none of these machines is equipped with dual cockpits. The Northrop LAS/WAVS simulator has been configured under a Navy contract to permit use as an air combat training simulator by addition of an instructor control and display console.

This review indicates there are four simulators, SAAC, LAMARS, AWAVS and LAS/WAVS, that are equipped with wide angle visual displays, target image generators and motion systems. Because of performance deficiencies in the SAAC motion system and delays in the computer it is not considered to be a suitable

machine to use for research on the importance of motion cues. This leaves LAMARS, AWAVS and the Northrop LAS/WAVS simulators as currently available ground simulator tools for research on the importance of motion to air combat training.

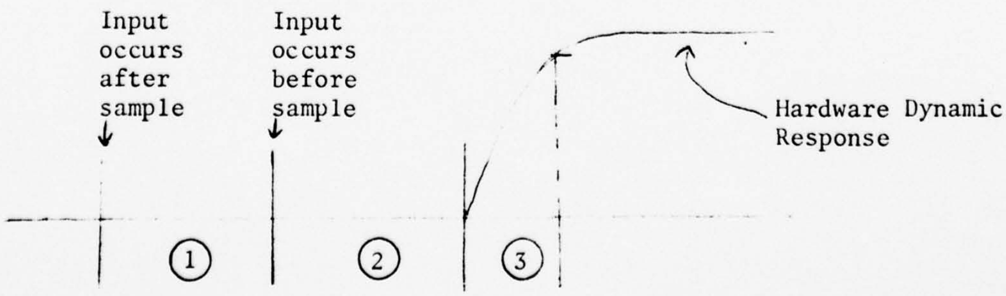
There is a need for research to establish motion system hardware performance, motion system drive algorithms and limits on time delay. There is a need for research and development of force cueing devices, drive algorithms for these devices when used in fixed base simulators and also when used in simulators with motion systems. There is also need for basic research on the human sensory mechanism to establish which cues are needed and the fidelity of replication required.

TIME DELAY AND LAG

This problem has been discussed under a number of other sections of this report. It has been made a separate topic under Problem Areas Requiring Research and Development to emphasize the importance the problem deserves. Full Mission Simulators are planned that attempt to simulate all aspects of a complex aircraft including the visual scene, radar images, other sensor images, weapon systems, enemy aircraft and also include instructional features. The computation load will be large and the software extensive. Because of this there may be requirements for use of floating point arithmetic and high level languages. These features will further increase the required computer capacity. A factor in determining computer "size" is the required iteration rate. It is of concern that aspects of the simulation that effect pilot closed loop control of the aircraft receive priority in computer allocation and timing so that dynamic closed loop control by the pilot is not compromised. Computation of aircraft motions, visual scene update, commands to motion and force cue devices, dynamic response of simulator hardware are all involved in piloted closed loop control. During the survey interviews, information was collected on the time delays and hardware lags that various simulators have and what the experience of various groups has been concerning this problem.

The time delay experienced with digital computers and simulator hardware can be divided into three segments.

1. Sampling interval
2. Computation and Output.
3. Hardware dynamic response.



The time delay caused by sampling is a uniformly distributed random variable which depends on when the control input occurs relative to the sampling time. This time interval can vary from zero to one iteration interval. The computation and output time will be assumed to be equal to one iteration interval and the hardware dynamic response may be described in terms of the time to 69% of the commanded response. The delay and lag values quoted by various groups are summarized below.

Iteration Rate	Sample Delay	Compute and Output	Hardware Lag	Total Delay
Values required to prevent noticeable effect on flying qualities:				
40/sec	0 - .025 sec	.025 sec	.056 sec	.081-.106 sec
Typical values in engineering simulators:				
33/sec	0 - .030 sec	.030 sec	.056 sec	.086-.116 sec
Some training simulators:				
20/sec	0 - .050 sec	.050 sec	.056 sec	.106-.156 sec

ASUPT

System	Software Delay	Hardware Delay	Total
Visual	.043-.110*sec	.083 sec	.126-.193*sec
Motion	.067-.200 sec	.200 sec	.267-.400 sec
G-seat	.067-.200 sec	.225 sec	.292-.425 sec
Aircraft Instruments	.133-.200 sec	Assumed small	.133-.200 sec

*Time compensated by .067 sec after problems encountered in formation flight simulation.

These numbers show that ASUPT (and also SAAC) has relatively large computer and hardware delays which have caused control problems and also cast doubt on data generated by this simulator relating to motion system utility. Computer

iteration rates of 40/sec are indicated to minimize the effect of time delay on flying qualities. The effect a given lag causes is a function of task and airplane dynamics.

There is a need to better define limits on time delays that can be tolerated and tolerances on synchronization of various simulator cues. In an airplane the motion and visual worlds are implicitly tied together with acceleration-velocity-displacement occurring in that order with visual perspective being related to displacement. In a simulator, however, the visual scene motion and platform motion are usually independent and the visual scene motion may lead platform motion cues.

VISUAL IMAGE GENERATION AND DISPLAY

Although ground attack and air combat simulators have been built and are being used to advantage there are major problems in image generation and display which restrict the utility and reduce the validity of the training that can be done. These problems are well recognized and considerable R & D money is being invested by government agencies and industry in attempts to develop technical concepts and equipment. Visual scene simulation is a highly technical field involving many disciplines such as optics, television, electronics, electro-optics, servodynamics, human perception, etc.. The Calspan personnel who performed this study made no attempt to evaluate whether or not the technical approaches being funded by the government are the "right" ones. The simulator deficiencies which require improvement are listed below, the technical difficulties encountered in attempting to make improvements are dependent on the combination of image storage, image generation, image relaying and image display hardware that is being considered.

Simulator Visual System deficiencies for air combat:

- Target image resolution at ranges of 2-3 miles.
- Ability to display multiple aircraft images.
- Ability to display aircraft at formation flight range as well as 2-3 miles.
- Altitude cues.
- Velocity over ground.
- Wide field of view.
- Image brightness.
- Image contrast.

Simulator visual system deficiencies for ground attack:

- Wide field of view in combination with high resolution scene detail.
- Moving targets.
- Gaming area size.
- Ground defensive fire.
- Color

- Varied ground lighting.
- Combined display of high resolution, wide field of view ground scene and multiple aircraft images representing attack team-mates or enemy air defense.
- Time delay in correspondence with aircraft motion.

RADAR SIMULATION

Radar systems are an important part of tactical aircraft weapons systems and navigation systems. Simulations of radar systems in the F-4, F-14, and E-2B aircraft were described as useful and effective for training, but, as the student progressed, there would come a time when the radar simulation would not adequately represent effects that were important to the interpretation of radar displays in the airplane. The factors requiring improvement were image realism, cloud effects, atmospheric effects, clutter, jamming, and land mass simulation.

Simulation of radar land mass is a major problem that is receiving attention by a number of companies and the Defense Mapping Agency.

One of the principle difficulties in land mass simulation is to generate the data base. Although large areas have been previously included in radar landmass systems, both analog and digital improvement in both radar systems and simulation systems implies a need for an improved data base. Although ways of producing terrain elevation data automatically do exist, both from maps and from photographs, adding cultural data and radar reflectance data require a large number of manhours, especially for areas of higher resolutions.

For digital systems, the large amounts of data stored and the requirement for fast access to some of the data has led to the requirement for elaborate data retrieval systems. At present, the only economic way to store such magnitudes of data and have rapid access is by using disk memories. These data then must be transferred to a faster type memory to enable the radar equation processor to operate at the high speed necessary for realistic simulation.

The time delay caused by the last data transformation and computation steps can be significant even at the high computation rate used. This is because "pipeline" processors are used where several elements do part of the processing and pass the result to the next element. If the data used to determine the position of a point on the display is 50 ms old, for example, and the aircraft is traveling at 1,000 ft/s, the error in the displayed image will be 50 ft.

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FLIR AND LLLTV SIMULATION

The following assessment of FLIR and LLLTV simulation is taken from a paper authored by Steve Johnson of Calspan Corp. titled "Simulation for Sensor Operator Training." The paper is based on work performed by Calspan to develop a training system for the aircrew of the Air Force B-1 strategic bomber.

Forward-looking infrared (FLIR) and low-light level television (LLLTV) are discussed together in that much of the technology of the two is related. The introduction of forward-looking infrared and low-light-level TV sensors on aircraft in the last few years, has posed new requirements for training and simulation. The ability to generate images for these sensors is still being developed. Important uses of these sensors are to confirm the identify of targets and of navigation checkpoints during low level flight.

There are a number of problems yet to be solved before a FLIR or LLLTV simulation is ready for inclusion in training devices. This includes the definition of which sensor effects are important for training and efficient ways to simulate them. Sensor effects include optical effects such as resolution limits, contrast reduction, and noise; and in the FLIR sensor, streaking due to gain variation. Also to be determined for FLIR simulators, are ways of generating surface brightness as a function of material and time history (temperature, time of day and season) or whether these detailed differences are important or not. Answers to questions relating to how many gray levels are necessary to cover the range of tones and not create artificial boundaries on smoothly changing surfaces, are required. Similarly, studies are required to establish how much detail is required in the presentation, as it would be very difficult to produce real world detail over large areas, and is probably not required. Another area for study is what weather effects are important and how to include them. Other problems have to do with the generation of a data base once the required characteristics are known. Because the resolution of the FLIR and LLLTV sensors is much better than that of a radar, the data base for these simulations could take much longer to generate. It is not yet known, however, how much detail is necessary to define a building for example.

There are several possible methods to generate FLIR images in a simulation environment. General Electric has demonstrated that computer generation of the images is quite feasible. The volume of data that would be required if a large area were digitized for simulation would lead to a data retrieval system as complex as that used for radar landmass systems. The data retrieval system would be complicated by the fact that there is no well defined maximum range as there is in radar systems. The time delay in the scene generation system, especially if a digital system is used, could lead to errors and difficulty in synchronizing the display with other sensors. The computing power required is no more than that required for visual computer generated imagery (CGI) and probably less because of the resolution and field of view limits of the sensors. The total delay in presenting the image may be slightly greater because of the extra processing to include sensor effects. Singer has proposed using the same off-line data base for the generation of FLIR images that will be used to generate radar images for Project 1183. This would probably be sufficient for relatively high altitude images, but may not contain enough detail for low level flight.

The Boeing Company has employed a film strip based system for presenting IR images. The advantage of this system is a realistic level of detail in the display. Disadvantages are lack of flexibility and, because the film is exposed at a higher altitude than that at which it is played back, the masking effects are not realistic.

It has been suggested that the film plate technology used for radar land mass simulations be adopted for FLIR simulation. A breadboard system is being implemented at the Naval Training Equipment Center. Most of the disadvantages of this method as applied to radar simulations, apply to IR simulation, but it does allow more flight path flexibility than the film strip method. The techniques for converting altitude information to perspective and masking information in real time have not been successfully demonstrated.

Redifon has produced model-type FLIR displays by using the same basic equipment as their model-type visual displays. This approach should allow realistic looking displays of a limited area. The disadvantages are limited flexibility in scale changes or new areas. Techniques similar to those used in visual simulations could be used, but special processors would be needed for sensor effects.

A set of digital computer programs has been written by General Electric to produce simulated FLIR images. The purpose of the simulation is to determine the characteristics required of a satisfactory FLIR sensor simulation with particular application to training. The simulation is organized much like G.E.'s visual simulation. Objects are stored as polyhedra with faces assigned brightness values. Geometric computations include projection to a viewing plane, tests for an object partly or entirely in the viewing frame, and tests for object overlap. Atmospheric effects at present include exponential contrast reduction. Images have been produced which appear to satisfactorily introduce sensor effects such as noise, edge blurring (an effect on resolution of the optical transfer function), and streaking (an effect peculiar to IR sensors because the picture is scanned with nonuniform sensors). The data base consists of three target areas containing a few cultural features and simple vegetation. The cultural features are, in general, low profile buildings and include a tank farm. Seasonal effects are not simulated; however, a range of brightness values associated with daytime or nighttime conditions can be inserted into the program. Also the effect of changes in sun angle or moon angle can be inserted through changes in computer software. This work was funded by the Human Resources Laboratories, Wright-Patterson Air Force Base.

Section VII

OTHER PROBLEM AREAS

CERTIFICATION, MODIFICATION, REVALIDATION

As the inventory of simulators increase there will be a growing burden of testing to support certification of simulators for specific training applications and as aircraft and weapon systems are modified, it will be necessary to update the simulators and revalidate the certification of the simulator for training. The modification to simulators can be extremely costly and unless well managed and coordinated may result in extensive downtime and disruption of training schedules. At the time of this review the Navy and Air Force had not yet finalized the approach to be used to deal with these problems. Both services were aware of the need to give attention to the problems and were in the process of formulating directives or organizational schemes to deal with them. The simulators being procured are complex devices with new and highly specialized equipment. The operations, maintenance and modification costs must be planned for and not underestimated. The Navy budget for simulator maintenance was quoted as \$125M compared to \$40M for procurement. There were expressions of worry from officers interviewed about the potential escalation of the O & M and modification costs as more simulators are put into the field. There were also expressions of doubt about the overall cost effectiveness of simulators when life cycle costing is used that includes costs of modifying the simulators to keep them current with the aircraft.

There is also a need to establish procedures for ensuring that simulators are kept updated to be consistent with the aircraft that they represent.

TRANSFER OF TRAINING

During the survey interviews a topic discussed was transfer of training or how is a simulator worked into a training program. It was generally agreed that controlled transfer of training experiments are difficult to perform. In fact, one person stated that transfer of training is a concept and not an experiment. Another observed that people have been working the transfer of training problem for 25 years with no great progress. The approach advocated by Air Force personnel is first to acquire the simulators, next run test and evaluation to establish what tasks the simulator can be used to train and then explore through operational test and evaluation how effective the simulator training is and experimentally determine the balance between simulator training and flight training in the aircraft.

It was observed by Navy personnel that training experiments are difficult to conduct because you are dealing with people's careers and lives. The experiments are performed in a dangerous environment and you can't let people get killed or have a career disadvantage because of a desire to test a training method. Because of these circumstances both the Navy and the Army are nibbling at how much instrument training can be done in simulators such as the T-2 (2F-101),the TA-4 (2F-90) and the UH-1 (2B-24) and how much must be done in the airplanes. Everybody agrees that crews must be exposed to the flight environment to learn the reality of the flight situation. It takes a long time and is expensive to determine the trade that can be used for instrument flight training, which is relatively straightforward; tactics is less well understood and one can only guess at the simulator role.

Some argue that training hours do not equate to proficiency and that each step of the way the student must be required to demonstrate accomplishment of task standards. This leads to the need for definition of what are termed Criteria Reference Objectives and the requirement for performance measures to objectively determine when the student has met the CRO. This is the main tenet of the ISD method. There are weaknesses and problems in this approach, however, because in general it is not easy to objectively measure performance even for relatively simple tasks like a GCA approach. The Navy experience with automated GCA training and objective grading was that there were so many shortcomings

they do not use it anymore. A GCA approach lends itself to performance grading but even this was found to be very difficult with too many variables to consider to make a grade purely objective. Many people believe that it is necessary to rely on subjective grading by expert instructor pilots.

The ISD method requires identification of training objectives which must be written up in behavioral terms or Criteria Reference Objectives. The student is then trained until he meets these objectives. As was discussed above objective performance measures are ideally required but subjective judgment can also be used and is usually required in the airplane because of performance measurement difficulties. The number of trials to reach criteria performance is used as a measure of the simulator training program effectiveness. By running parallel classes with and without simulator training you can see if fewer trials are required to achieve criteria performance in the aircraft by students who receive simulator training. This kind of experiment is proposed for establishing the balance of simulator and aircraft training by Air Force personnel.

The training trials to criteria reference is preferred by some over the training effectiveness ratio advocated by others because the "number of trials" approach permits accounting for "overhead" time in the airplane, i.e. time required for preflight, takeoff, flight to and from the training area, and landing for a session to be devoted to training the student to do steep turns.

The problem of determining how to use a simulator in a training program continues to require attention. In the environment of official policy to increase simulator use there is a danger of proceeding too fast, i.e. making optimistic estimates of the amount of training that can be accomplished in the simulator.

SOFTWARE MANAGEMENT

Full Mission Simulators and Weapon System Simulators use digital computers for many aspects of the simulation, consequently extensive software is required. The task of documenting and controlling the software over the life of the simulator to accommodate design changes and data revisions will require considerable effort. There must be centralized control of software to maintain standardization of performance of simulators located at various bases. This requirement will take an additional importance if student performance in the simulator is to be measured and graded.

APPENDIX A

OBSERVATIONS BY CALSPAN ENGINEERING PILOTS ON VARIOUS SIMULATORS

The observations and impressions recorded by the Calspan engineering pilots after their exposure to the various simulation devices are recorded in the following paragraphs. These observations and impressions are based on brief sessions in the simulators. The Calspan pilots were usually accommodated on a courtesy basis between scheduled sessions and usually took the form of dynamic demonstrations of the various simulators. No quantitative data was taken during these sessions.

Luke F-4 Simulator - pitch, roll, heave

1) Very sensitive in pitch.

2) Airplane dynamics very difficult to see because pitch response was overdamped.

3) Roll was very stable, very little attention required for proper roll control in instrument maneuvers.

4) Motion was helpful in obtaining better pitch control but tended to complicate roll because of the side accelerations introduced as the cockpit rolled. Not really objectionable, however. The washout circuits in roll were quite noticeable, i.e. well above my motion threshold level.

5) Cockpit was an exact duplicate.

6) Radar display was probably better than what people see in the real airplane;display was easy and natural to fly.

SAAC Simulator

1) Display actually pretty good; target size changes size as it goes from one mosaic to another. Two dimensional image makes it difficult to determine relative motion. Two dimensional perspective is good but the difficulty with being able to see three dimensional relative motion often makes the target look like it does weird things, like change attitude about its own axis without a proper change in range.

2) Most probably due to computational errors, but it is almost impossible to fly formation or track closely without getting into a longitudinal PIO. Can't fly any closer than 100 feet without losing the display. 400 feet was given as a more realistic formation distance.

3) Pitch dynamics very difficult to see. Roll was much more sensitive and difficult to control than I would have liked. I almost always over-controlled the airplane in roll. The visual seemed almost a blur as I did aileron rolls. Loops were realistic but I had considerable difficulty judging or getting any altitude information from the visual scene. I almost always had to go inside to determine my altitude.

The most objectionable feature was my propensity to spin the simulator. I spun three times. There was little or no warning prior to spinning, i.e. no buffet.

It was difficult to project a flight path for the target airplane. I would see relative motion and mentally extend that to some future time and invariably the target airplane would seem to make much sharper turns than I projected. It was always easy to pick out the target because of its high contrast with the background scene.

It was very difficult to get a good three dimensional feel for the ACM. I flew my opponent into the ground at least once.

It was relatively easy to tell whether the motion was on or off, not because it made a major difference in my performance, but because it was much smoother with the motion turned off.

Kingsville - A4 Simulator

The simulation of the A4 seemed to have one noticeable deficiency and that was the light Dutch roll damping with the dampers turned off.

The cockpit was an exact duplicate of the A4 with some additional controls for the simulation. Basic simulation seemed to be adequate. However, I never really felt as comfortable with the CGI as I had hoped I would. There were several obvious problems. First, altitude was extremely difficult to judge, especially during landings. It was kind of a guess as to when to flare for a landing touchdown. When getting close into the field or target, added features would simply pop into view. Attempts at flying the mirror for a Carrier approach were totally unsatisfactory. The most impressive display was their air-to-ground display and I had considerable difficulty with that one. It was difficult to determine when to start your turn onto the run-in-line for tracking. I guess if one had more time, one could have learned to do the task and gather good information.

I was indifferent to motion as far as being helpful or detrimental.

Williams - ASUPT

I had only a small exposure to the ASUPT and only for the landing approach task. My first impression was that the simulated T-37 was considerably better damped both longitudinally and lateral-directionally than a T-37 could possibly be.

Takeoff simulation lacked a good feel for side acceleration and runway roughness, however, it was adequate. Power response and aircraft performance seemed to be about what I would expect. As mentioned above, the airplane seemed to be well behaved and most probably overdamped to pilot control inputs. The only portion of the visual display that had good definition was the immediate area around Williams AFB. Once you got away from that area, it was quite difficult to obtain good altitude information from the visual scene. The lack of altitude information was quite noticeable during the landing approach, in that the altimeter becomes the primary cue as opposed to the outside world. There was little or no tendency to get into a lateral "wing rock" during the landing approach.

The motion system was not very noticeable in that I don't remember it providing either positive or negative cues.

Cockpit duplication and engine sound effects were excellent. Runway roughness and associated noise would be a useful addition.

ACES

ACES evaluation was somewhat limited because of time but I did have several observations. There was a real tendency to totally forget about the airplane when you were flying. This is somewhat unrealistic because you still have to worry about the health of the airplane. When I observed other pilots, they and me too, tended to be in full afterburner or idle and to sharply slam the throttle from one extreme to the other without regard for any consequences. There was little or no attention paid to angle of attack or "g" restrictions. The fight was totally outside and pilots did what ever was necessary to go where they wanted without any worry about spins or overstress. The visual presentation was actually pretty good as far as target perspective was concerned. The greatest

deficiency was in not being able to determine height above the ground and relative motion with respect to the ground, certainly the two are related. I was disappointed in the ability to track the target airplane in the guns mode. It was not possible to obtain a smooth continuous track. You had to simply fire your guns as you passed through the target and hope that you could achieve a hit.

I was a little surprised to find that most of the air-to-air engagements ended in horizontal turning fights with very little vertical maneuvering. I think this is possibly due to the lack of altitude cues and therefore the pilots lack some feel for the three dimensional aspect of the fight.

I suspect that much of the scoring criteria such as fuel used and ammunition fired, etc. are concerned with items that the pilot really doesn't attempt to control in this environment.

American Airlines DC-10

The realism of the visual scene for the landing approach was the best I have seen. The excellent attention to detail of the objects near the runway I feel added a lot to this realism. Of course, the visual scene was used only for the landing and it seemed quite adequate for this task. Most of the information for the control of the airplane comes from the instruments as opposed to the visual including the cue to flare the airplane. In other words, there seemed to be a lesser requirement for the visual scene than in most landing approach simulations. Touchdown and runway roughness cues were excellent.

I also suspect that the simulator dynamics are probably representative of the DC-10.

There was a noticeable lack of lateral PIO's that are often seen in landing aprpoach simulations.

I was somewhat indifferent to the motion cues as what we saw seemed quite adequate.

American's attitude toward simulation is certainly excellent, but probably should be checked out with some of their line pilots. My American Airline friends seem to have many of the same comments about AA fight simulators as do other Air Force or Navy pilots.

Williams Formation Trainer

Flying the formation trainer was almost an afterthought during the visit to Williams AFB. However, a short flight was accomplished.

First of all, this was the first ground simulator in which I was able to fly close formation. The two dimensional target airplane provided a realistic display for formation. It was possible to fly wing, practice cross-under maneuvers and fly trail formation. Some rendezvous practice could be accomplished.

The trainer destroyed one of my preconceived notions in that I was convinced that formation was indeed a three dimensional task and would not lend itself to a two dimensional display. I felt that the visual perspective provided in this trainer was adequate for initial formation training.

The cockpit and controls were highly simplified. I felt that airplane dynamics were probably considerably different from the T-38 airplane. The basic airplane was very stable and highly damped. It was my understanding that several sets of equations were programmed to represent the airplane, however, only one set was flown.

The target airplane was capable of being maneuvered through a series of flight maneuvers for formation practice. In general, I was quite impressed with what had been accomplished with a rather austere device.

NASA Langley DMS

During my recent week at Langley I had the opportunity for a brief flight (15 minutes) in the DMS; since you are presently surveying simulation facilities, I thought my observations would be of some interest. The objective of the tests being conducted in the simulator during my visit was to evaluate the usefulness of a "g" seat to provide pilot motion cues in place of the "g" suit which is normally used. An F-5E was the aggressor aircraft and an F-4E (with slats) was the target; target motion was computer controlled to do either high "g" turns or "bank-to-bank" maneuvering.

- I was unable to fly the DMS in a reasonable fashion. Since I had flown (in 1968) the prototype of the system and been very impressed with its potential, I was both embarrassed and disappointed with my performance.

- My observations must be qualified by the fact that I have not flown an F-5E (although I have flown the T-38) and I am hardly "current" in combat maneuvering.

- The "g" seat did not provide any meaningful cue for "g" levels. I was generally flying at very high angle of attack but I had no sense of being at high "g" and I could not use any cockpit information in the rapid maneuvering task.

- Control of the "pipper" was very sloppy even at the beginning of the tasks where the "g" levels were low. In particular, I could not stop the pipper from sliding well past the target laterally and subsequently over-correcting in the opposite direction. This problem was somewhat aggravated by my initial efforts to track at all times rather than maneuver to the tracking position and then try to track. Even correcting this problem did not produce reasonable performance.

- The target presentation was outstanding; even though its brightness was somewhat artificial, the visual presentation of target maneuvering was realistic, i.e. aspect was good. Agility of the target was surprising but perhaps slotted F-4's can turn in this fashion.

- Stick forces were <u>very</u> heavy (perhaps in part due to the high "g" levels - which were not otherwise apparent to the pilot); the whole aircraft had a "high inertia feeling".

- In passing, the DMS feel system was a 3-axis McFadden system. I also saw the 4-axis system which McFadden has sold to NASA for the CH-47 variable stability helicopter. They apparently use some sort of low friction oil bearing as the heart of their system.

In general, in spite of my negative comments, the facility was impressive; the people seemed very competent and technically motivated. The NASA project pilot said that most pilots took 6-8 hours to learn to fly the simulator but that, despite this indication that the real environment is not replicated, the transfer of training was high.

Ames FSAA

I had the opportunity to fly the FSAA as it was set up to simulate an advanced version of the Rockwell T-39 or Saber liner aircraft.

It was quite obvious that for this simulation there was a mismatch in the heave response of the airplane and the pitch response. There seemed to be much greater heave than was warranted for the small pitch angles achieved. Much of the flying period was spent investigating this problem.

Initial setup of the simulator was on the glide slope and localizer for an ILS approach. Since the airplane was handed off in a precisely trimmed condition and no turbulence was simulated, it was possible to fly a nearly perfect approach without touching the controls. When I did make deviations from the desired flight path, I was quite pleased with my ability to fly the simulator like an airplane. There was little or no tendency to get into a lateral PIO as is often the case on landing. There was some difficulty in judging altitude on the final approach and considerable attention to the instruments was required to determine the proper altitude. The visual scene did not have nearly the detail that I had seen say at the American Airlines simulator and I felt this degraded my ability to correctly judge altitude.

During the simulation, I was quite aware of the lateral motion of the simulator. This awareness was not due to the physical feel of the simulator but the whining sound associated with the lateral travel. There seemed to be very little pitch motion associated with the configuration being flown. I again point out the problem with the heave portion of the simulation because it was so dramatic. Not only did the airplane have much too high vertical accelerations associated with the pitch response, it also seemed to occur at a different frequency. The simulator people were actively trying to solve this problem. I repeat this because my impressions of the FSAA are clouded somewhat by the attention paid to this deficiency during my short flight in the simulator.

There is little doubt that the motion system on the FSAA is excellent. The visual could provide greater detail in close and I feel that would be an improvement.

A demonstration of the "in weather" capability of the simulator was given. For those situations where the clouds have a uniform base with excellent visibility underneath the weather display is excellent.

There was a slight pulsing in the feel system for the light force gradients being simulated. This pulsing was not degrading, however, it was noticeable.

Kingsville, T2C Simulator

The T2C flight simulator was an excellent instrument trainer. The duplication of the T2C cockpit was excellent. The navigation and instructor display consoles were quite sophisticated and highly capable.

The flight characteristics of the simulator were quite adequate for the instrument task.

It is my opinion that the motion system was good and certainly highly desirable for the instrument training task. I feel that motion is particularly desirable for early instrument training. A large part of instrument training involves teaching the pilot to overcome the reliance on motion cues and to trust the visual cues obtained from the instruments. To this extent some motion, even incorrect motion, is beneficial for instrument training. The turbulence simulation was good and also highly desirable. Gust cues alert the pilot to increase his scan as some type of aircraft upset is about to occur.

Flying the T2C simulator did not present any major difficulties. Power settings and performance characteristics were about what one would expect.

One overall observation was that the simulator and simulator console capabilities seem to be considerably more complex than was really necessary. Instructor pilots indicated they never came close to using the full capability of the simulator. Complexity of the simulator and length of instructor pilot training was noted as one reason for the less than total use of the full simulator capability.

UH-1 Helicopter Simulator

The UH-1 helicopter instrument trainer was an interesting simulator. Cockpit realism and dynamic simulation was excellent. The motion and audio simulations were excellent. It was possible to provide the proper motion and noise to go with things like blade imbalance. Emergency simulations of things like control system hardover were excellent.

Simulator and operator console capability were excellent. Navigation and instrument procedure training capabilities were outstanding. The simulators included self teaching and evaluation programs that allowed additional student training without the requirement for a full time instructor.

A most graphic demonstration of the desirability of motion for the helicopter simulator was provided. Attempts were made to accomplish an instrument takeoff. It was almost impossible without motion and relatively easy with motion. It was extremely difficult to determine if the helicopter was straight or turning without motion. A similar difficulty was seen for auto rotation with and without motion. It is my opinion that a motion system is a must for both helicopter instrument and emergency procedure training.

APPENDIX B

REVIEW COMMENTS

Draft copies of the two volumes of this report were reviewed by representatives of the following DOD Offices and Departments:

1. Office of Assistant Secretary of Defense
   Manpower and Reserve Affairs
2. Office of the Director of Defense Research and Engineering
   Research and Advanced Technology
3. Department of the Air Force
   Headquarters United States Air Force
4. Department of the Navy
   Office of the Chief of Naval Operations

The cover letters and detail review comments returned by these reviewers are included in this Appendix. The authors have responded to a number of the review comments and have revised or added to the texts of the reports. Many of the review comments, however, express a different point of view or provide additional information that the authors believe should be made available to the reader and for this reason the review comments have been included in their entirety.

OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE
WASHINGTON, D. C. 20301

October 19, 1976

MANPOWER AND
RESERVE AFFAIRS
(Planning and Requirements)

MEMORANDUM FOR Major G. W. Burkley, OSD (P&E)

SUBJECT: CALSPAN Simulator Study

I have reviewed the draft report in the time available and provide the following candid staff comments.

The first complete paragraph on page 12 of the report implies that the OASD(M&RA) was directed to prepare simulator tradeoff analyses. The implication is not entirely correct. The August 14, 1973, letter initiated selected projects in an effort to improve the effectiveness of defense spending in relation to force structure and military capability. The ASD(M&RA) was identified to provide leadership for the project on simulators. A project plan was developed and provided to the ASD(C) on 7 September. The project plan outlined the OSD staff responsibilities for the project. A copy of the August letter and the Project plan are attached.

With regard to the last paragraph on page 12, I have attached a copy of PA&E's coordination on the congressional interest letter to Mr. Hebert. The letter was revised to incorporate PA&E's suggestion (copy attached).

It is suggested that the first paragraph on page 12 be revised to correctly relate the facts and that the last paragraph on page 12 and continued on page 13 be replaced by a paragraph similar to the following:

> In 1974, the DoD Study Group on Flight Simulation proposed a planning goal to reduce flying hours by 25% in the next five years. This ambitious goal was proposed to indicate the level of concern over possible future fuel nonavailability due to either embargo or high cost and that

higher Service priority should be given to funding simulator programs. The 25% reduction goal became widely publicized and although it was not intended as a directive, the Services initiated plans for significant simulator investments.

The last sentence of the paragraph regarding Air Force simulator investment plans is incorrect.

In general, the report is a compilation of the author's opinions concerning flight simulation and includes statements which cannot be supported. For example, on page 26 the report states that there are examples of elaborate and expensive simulators that fall short of expectations and as a result are an embarrassment to <u>all</u> involved. This is just one example of the exaggeration found throughout the report. In other cases words and phrases such as "unacceptable" and "not considered to be a useful device" are used to describe simulators. Yet, there are no objective performance data or statistical analyses presented to support the statements. At the same time, the statements are made as though they are widely held and even "unanimously" supported by military personnel.

Conclusions that are not supported by objective performance data should be expressed as the author's opinions. They are opinions that were held by the author either before the study was initiated or developed after interviewing base level flight operations personnel whose opinions are driven by their concern over losing flying time rather than developing the most cost effective mix of ground simulator and aircraft training time.

The report also contains errors in fact. For example, the report refers to the 2B 24 training device as a cockpit procedures trainer when in fact it is a rather sophisticated instrument flight training system. The reported cost per hour for operating the device and the cost per flying hour for the UH-1 are also not consistent with current Army cost factors. Further, the report states that pressure to reduce cost and to conserve fuel have forced those responsible for developing training syllabi to attempt to reduce the flight hours in the aircraft to a minimum and to accomplish training to the desired proficiency mostly in the simulator. Even if a 25% reduction in flying hours were achieved, as ambitious as such a goal is, 75% of the no simulator flying hour requirement would remain to be accomplished in actual aircraft. That is a far cry from "training to the desired proficiency mostly in the simulator."

I recommend that a disclaimer be inserted in the preface of the report to insure that readers do not accept the ideas and opinions expressed in the report as those of the Department of Defense.

L. G. Junkmann
Lt. Col., USAF

Attachments

THE SECRETARY OF DEFENSE
WASHINGTON, D.C. 20301

AUG 14 1973

MEMORANDUM FOR Director of Defense Research & Engineering
Assistant Secretaries of Defense
Director of Defense Program Analysis & Evaluation

SUBJECT: DoD Overhead and Support Projects

The Department of Defense should initiate selected projects which will improve the effectiveness of defense spending in relation to force structure and military capability. We have, of course, been pursuing this objective aggressively; but we can give increased emphasis to selected projects at this time.

Several projects are suggested in the attached schedule, and I have asked the Assistant Secretary of Defense (Comptroller) to coordinate this effort for DoD. Specific leadership for each of the suggested projects follow:

Headquarters	ASD (C)
Reserve Forces	ASD (M&RA)
Military Health Care	ASD (H&E)
Base Closures	ASD (I&L)
Contracting Out	ASD (I&L)
Simulators	ASD (M&RA)
Modernization	Director, DPA&E

The Comptroller will arrange for a meeting with you to discuss the planning for these projects.

The considerable prior effort and accomplishment in each of the project areas should provide a starting point for further work. When your plans have been developed and coordinated with the Comptroller, I shall review them.

W. P. Clements, Jr.
Deputy

Enclosure

(3)

6 September 1973

Project Plan - Simulators

Objectives:

1. Insure the research and development, acquisition, and utilization of simulation devices.

2. Promote the maximum use of flight simulators consistent with effectiveness of training, costs, and operations.

Issues:

- Identification of the most immediate and effective action for increased simulator use with least risk to operational capability.

- Identification of reduction of flying hours made possible by increased simulator use.

- Disposition to be made of resources saved

  -- Reduction of allocated flying hours and related resources.

  -- Reduction in procurement of training and operational aircraft.

  -- Development and procurement of additional simulators.

  -- Increase aircraft to tactical units.

  -- Increase allocation of flying hours to currently deficient areas.

  -- Increase research and development simulation technology.

Task Plan:

1. Identify the points of contact in DOD components who will serve on the study effort.

2. Review the current flight simulator status in terms of research efforts, technology, production capability and operating inventory.

3. Develop a program for increased simulator use on the basis of least risk to operational capability.

   a. Identify any savings relative to FY 1975 budget.

   b. Provide recommended locations for simulators to insure maximum utilization.

   c. Identify increased needs for development and procurement of simulators.

4. Increase the use of simulators in proficiency and advanced flight training.

5. Increase the use of simulators in undergraduate training.

6. Identify O&.. savings beyond FY 75.

7. Reallocate support/training aircraft.

8. Continuously evaluate training and cost effectiveness.

9. Regulate simulator and tactical and training aircraft buys on the basis of results.

Timing

- Items 1 and 2 on the Task Plan - 15 Oct 73.
- Item 3 on Task Plan - 9 Nov 73.
- Items 4 through 7 on Task Plan - 1 Apr 74.
- Remaining items are a continuous effort by appropriate staff agencies.

Staff Requirements

- M&RA will:
  - -- Serve as overall project coordinator and chair the study effort.
  - -- Provide guidance to the military services on the training effectiveness of simulators versus operational aircraft.
  - -- Develop the report from the data provided by participants to guide the SecDef decision on simulator development and utilization.
- DDR&E will:
  - -- Provide data on the state of the art in flight simulators.
  - -- Assist the Services in the determination of payoff through increased use of flight simulators.
  - -- Provide guidance on research and development to correct recognized deficiencies.
- OSD Comptroller will:
  - -- Direct the military services in the identification of costs associated with procurement and operation of simulators and aircraft.
  - -- Reflect the impact of dollar savings in the appropriate FY budget submission.
- OSD(PA&E) will:
  - -- Provide the analytical support needed to determine where initial reduction in procurement or training can be made.
  - -- Assist in the determination of tradeoffs for resource disposition.

The Military Services will:

-- Participate in the determination of the flight simulator/operational flying tradeoffs.

-- Participate in the determination of recommendations for the disposition of resources made available.

-- Revise their training schedules to reflect tradeoff decisions.

-- Submit their budget requests and revise existing budgets to support decisions.

OFFICE OF THE DIRECTOR OF
DEFENSE PROGRAM ANALYSIS AND EVALUATION
WASHINGTON, D. C. 20301

15 FEB 1974

MEMORANDUM FOR LIEUTENANT GENERAL R. L. TABER, OASD(M&RA)

SUBJECT: Response to Hebert Letter Regarding Underutilization of Simulators

I will concur in the letter if one additional point is added. I request the following be added after the second sentence in the third paragraph (i.e., following "increased funding support"):

> Although the current state of the art would not allow this goal to be reached, the Department will take actions to accelerate development programs which, if successful, may enable us to achieve the 25% goal. In support of this, the FY 75 budget contains _____ million for development for aircraft simulators.

I have checked this with General Furlong who agrees it would be a useful addition.

John D. Christie
John D. Christie
Principal Deputy Director

THE DEPUTY SECRETARY OF DEFENSE
WASHINGTON, D. C. 20301

FEB 20 1974

Honorable F. Edward Hebert
Chairman, Committee on Armed Services
House of Representatives
Washington, D.C. 20515

Dear Mr. Chairman:

As Mr. Brehm advised you on 21 December 1973, a review of the use of simulation in military training programs has been conducted. The Services have done extensive research in the area of simulation and are using significant amounts in their training programs. They have programmed new devices that have proven effective and developed additional requirements in a number of areas. There are areas where fiscal restraints, inadequate technology, and mission priorities may have precluded simulator procurement. We are reemphasizing the need to increase simulator use. To this end we initiated a Department of Defense study aimed at reducing operating costs through increased use of flight simulation.

A task group was formed in September 1973 to accomplish this objective. The group's initial efforts were largely responsible for the addition of a total of $164 million to the FY 74 supplemental and FY 75 Defense budget requests. The budget request for flight simulation in FY 75 is $377 million. The task group is now in the process of developing a master flight simulation plan which will be a Department of Defense guide through the end of the decade. This plan will include tradeoff analysis and will identify need for research and development to overcome technological deficiencies, such as currently exist in the area of high fidelity visual displays.

The study group has established the goal of reducing flying hours by 25% in the next five years. Attainment of this goal is dependent upon advancement in technology and increased funding support. Although the current state of the art would not allow this goal to be reached, the Department will take action to accelerate development programs which, if successful, may enable us to achieve the 25% goal. In support of this, the FY 75 budget contains approximately $23 million for development for aircraft simulators. We have purposely set our sights high, but, as we look to examples set by American Airlines, where 90% of their training is now done in FAA certified simulators, we think that the goal is

realistic. It will take about 30 months to begin to realize the initial cost savings related to current procurements because of the long production lead time, but unless we vigorously attack the problem now, we will only delay the eventual realization of our goal. When programs for increasing flight simulation are established, we will shift the emphasis to include other areas of simulation.

We are convinced that simulation is the answer to many of our training needs and offers many advantages. Consistent with objective management practices, we will continue to explore every practical avenue of increasing our efficiency. We expect simulation to play a major role in this effort.

I appreciate the opportunity to address this issue. Should you desire, more detailed data relating to this area can be provided.

Sincerely,

Bill Clements

OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE

WASHINGTON, D.C. 20301

17 November 1976

MANPOWER AND
RESERVE AFFAIRS
(Planning and Requirements)

MEMORANDUM FOR Major G. W. Burkley, OSD (P&E)

SUBJECT: CALSPAN Simulator Report, Volume II

I have reviewed the draft report, Volume II, in the time available and, again, provide the following candid comments.

The report reveals discrepancies between information provided by the Services and that contained in the report. However, since the Services are also reviewing the draft, their comments will probably be more noteworthy than my understanding of their views.

In general, the draft appears to represent a biassed interpretation of the literature. For whatever the reason, the report seems to emphasize the limitations of simulation and ignores the contributions that can be made. The following paragraphs are specific page-by-page examples.

Page 6 - "In summary, it can be stated unequivocally that there are insufficient data available with which to perform hard trade studies to evaluate options." And, page 33 - "Thus based on the review of the literature concerning training device concepts and application of these features, one comes away with the impression that there presently exists no quantitative data that establishes their effectiveness." The civil airline experience and the results of a recent ARI study on the 2B24 are examples of proven effectiveness. It is hard to imagine how the airline experience could have been missed in a literature survey.

Page 11 - Paragraph 2. Whether an alternative to Apollo training existed or not has nothing to do with the feasibility of simulation as an effective training method. The fact remains that training was successfully accomplished through simulation.

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Page 13 - Fifth major heading. The statement is inaccurate. Freeze capability and adaptive training permit control over training not possible in actual flight.

Page 21 - "Thus the inability to describe a performance reference for the determination of device effectiveness (transfer of training) is a significant problem area." This is also true of tactical training missions in actual aircraft. The "operational situation" in peacetime is a simulation of wartime tactical operations. I am not aware of any data that indicates that peacetime tactical training in airborne simulators, currently used, is any better than that which could be provided in a ground based simulator used in conjunction with the airborne simulator. In fact, if the new generation of simulators that are possible ever get produced, they may prove to be more effective than the aircraft because of the safety of flight restrictions that must be exercised in actual airborne flight training.

Page 37 - "The implication of this study is that in the operational situation it may be more effective to provide training devices which can maintain procedural responses than to provide 'full mission' capability." It is impossible to make this statement based on the referenced study since the study does not address "full mission" training.

Page 37 - Second full paragraph. The reference to the TAC ACES II report is not relevant since learning how to perform a maneuver is different than learning how to teach or evaluate another pilot's execution of that maneuver.

Page 54 - "A survey conclusion is that 'the usefulness of the simulator for other than procedural work and emergencies was thought to be limited'." The statement may be true but is misleading in the context used. The limits of simulation are recognized. That is why 100 percent simulation is not considered feasible.

Page 59 - The literature survey must of necessity be limited to experiences with devices that were developed and that contained technology available prior to use and documentation. Therefore, "based on the literature survey," the statement that "the present level of simulation technology cannot justify any 'cost-effective procurement' " is unfounded.

As with Volume I, it is recommended that a disclaimer be inserted in the preface of the report to insure that readers do not accept the ideas or opinions expressed in the report as those of the Department of Defense.

LaVerne G. Junkmann
Lt. Colonel, USAF

OFFICE OF THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
WASHINGTON, D. C. 20301

14 DEC 1976

MEMORANDUM FOR DIRECTOR, PLANNING AND EVALUATION
(TACTICAL AIR FORCES)

SUBJECT: CALSPAN Simulator Study Contract MDA-703-76-C-0204

The draft of the final report of the subject study entitled, "An Assessment of the Role of Simulators in Military Flight Training" (Volumes I and II), by C. R. Chalk and R. Wasserman, has been reviewed per the request of Major Burkley. The purpose of the CALSPAN study was to provide "an independent assessment of the status of simulators and the role they should play in military tactical flight training." (p. 1, Vol I) "This assessment . . . was made on the basis of information obtained from a literature survey (Vol II), and a survey of individuals (Vol I) in industry and government agencies who are knowledgeable about flight simulators, military tactical flight training and related matters." (p. 14, Vol I).

Several important points are made in the reports upon which actions could be taken within the DoD to examine the implications of these points upon the development and use of flight simulators. These are listed in Attachment 1.

Major technical and methodological difficulties exist with the reports, especially with Volume I, which without careful and extensive editing to include documentation of the information presented will render the report of little practical use to the DoD in its decision-making process regarding simulators.

The difficulties with the CALSPAN Report (Volume I) are as follows:

1. Assessment based on survey interviews was not conducted in a systematic fashion. The various impressions, points of view, and attitudes found during the survey are reported, without evaluation, as if they were facts. No information is provided concerning the list of questions which was used in the interviews or that the same questions were used at each location visited. No tabulation

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of responses to questions is reported. Thus, it is impossible to assess the extent of agreement or disagreement on key issues among experts encountered during the visits. It is clear that items reported in the text have been selected from the mass of interview data to make points which may or may not be representative or supported by the data.

2. The report makes a major issue of using simulator training to supplement or substitute for aircraft training. In the ODDR&E view, the real issue is to determine the proper mix of facilities, equipment, training materials and procedures that will be needed to train pilots and other aircrews to train and maintain skills to perform specified missions at the least possible cost. The mix needs to be determined based on the instructional system development (ISD) model approach which permits various constraints to be applied when decisions are made concerning the appropriate mix of ground classroom training, simulator training and flight training required to reach the specified level of performance. The Executive Summary ignores that the ISD method leads to decisions concerning how training can best be accomplished. If the ISD process is appropriately done, the issue to "supplement or substitute" becomes a moot issue. This point was clearly discussed with CALSPAN during the initial meeting and then when the "in progress review" was conducted. It is clear from the report that the investigators failed to use or ignored the in-house CALSPAN expertise in the ISD area that would have assured that this area was properly covered. The advisability of using the CALSPAN in-house expertise was stressed in the initial meeting with the CALSPAN contractors.

3. The report made no useful distinction between out-dated technology which is still in use, current state-of-the-art technology available for present procurements and technology either in experimental use or thought to be feasible by in-house experts or simulator manufacturers. Thus, it is difficult to distinguish between complaints from those surveyed due to either inadequate simulators which will soon be replaced or due to developmental problems found with experimental prototypes and simulators currently being procured with proven technology. It also was not possible to distinguish between complaints related to technical features of simulators and those related to cost and management that have forced the DoD to use simulators rather than airplanes for some part of training.

4. The report neglects the need for pilot performance measures which are required to help resolve issues concerning transfer and level of training, fidelity of simulators, the technical complexity of simulators, and the proper mix of full mission and part task trainers.

5. The report offers no practical assessment related to the fact that most of the issues identified in the survey do require adequate cost and effectiveness data to permit resolution of the issues in an objective manner.

6. The background statement of the report is not particularly helpful. It is definitely stilted in terms of the emphasis on 25% reduction in flight time. If this is to be used at all to document what has been said from a historical perspective, a summary of the information in the Senate hearings on this issue, which have been available for some time, should be included.

The major limitation of the literature survey (Vol II) is related to the uncritical nature of the report with the exception of the A-10 trade study. The various summaries of the literature do not identify the methods of analysis used in the studies, they do not describe the data nor do they comment on whether the conclusions found in the studies are supported by data. Consequently, there is practically no basis on which to judge the accuracy and credibility of the findings throughout the report or in the Executive Summary.

The report makes the point that there is insufficient objective data available with which to perform hard trade studies to analyze various training options, or to demonstrate the increase in cost-effectiveness of tactical flight training simulators. It also makes the point that there is little "transfer-of-training" data to indicate the impact of various levels of cue fidelity or cue interaction (p. vii). While we agree that increased emphasis needs to be placed on both cost benefits and performance effectiveness methodology and study, we do not agree with the following conclusions which occur in the same paragraph:

> "The existing state-of-the-art appears to be limited in its capability to permit substitution of simulator hours for flying hours, except primarily for procedural (normal or emergency) and instrument flying phases. The state-of-the-art is sufficient to provide supplemental training in the tactical mission, provided the courses are tightly controlled.

The true value of many simulation capabilities, e.g., instructional features, is also not well understood." (p. vii)

These views may be held by some flying personnel, but they are not proven by any significant experimental data and cannot be supported by the evidence presented in the report. In fact, our assessment of preliminary experimental data and results obtained by the airlines causes us to challenge this conclusion. The last sentence is misleading. The value of instructional features on simulators is well understood on the basis of much performance effectiveness data, although few significant cost tradeoffs have been performed.

We discussed the issue of supplemental or substitute simulator training for aircraft training previously under Volume I, major difficulty #2. Those comments apply here.

Specific comments on various sections of the report are attached (Attachment 3).

Volume I, based on interviews, and Volume II, based on the literature, are companion reports of a single study, but no effort is made in either of these documents to relate one report to the other. Both documents make a major issue about the use of simulators, either to supplement or substitute for flying in aircraft. The issue of the specific mix of how much simulator time and how much aircraft time for particular aircraft and missions is unanswerable without an experimental program which uses performance measurement to determine which combinations of training in simulators and aircraft produce required performance in the least time and cost.

In conclusion, we reiterate that we do not believe that the reports will be of significant benefit to the DoD in its decision-making process regarding simulators. On the other hand, the use of these reports may serve to confuse decision makers, prolong the period before the DoD policy on the issue of the proper use and mix of simulators and flight time can be made, and be judged by Congress as unresponsive to its guidance to look into the use of simulators as a way of saving costs and energy.

John L. Allen
Deputy Director
(Research and Advanced
Technology)

Attachments

Important for Further Examination

1. Simulators provide many more failure states than can be fitted into the training schedule. Some instructors demand training on unrealistic numbers and combinations of failures. Action: Determine if large number of failure modes increases cost and complexity of simulator. Review selection of failure modes needed for training.

2. Improved math models of aircraft flight characteristics are needed to provide fidelity of visual and motion cues. Better models are needed for training pilots for maneuvering limits of modern tactical aircraft. Action: Review deficiency with a view of management of R&D program to eliminate the deficiency.

3. Larger computer capacity needed to reduce time delays on current simulators. Action: Procure additional computer capacity when required.

SPECIFIC COMMENTS ON VOLUME I

1. Report concentrates on tactical flight training but the title is, "Military Flight Training." Suggest that the title be changed to reflect the thrust of the report.

2. Sources of data should be identified in a list of references.

3. Some areas receive such inadequate treatment that they fail to contribute anything useful to the report. Examples are cockpit procedures, p. 26; alternatives to simulators, p. 66; certification, p. 91; and software management, p. 94.

4. The description of cockpit procedure trainers and instrument flight trainers on p. 26-27 and p. 1 gives a completely erroneous impression of what can be accomplished in a device with the sophistication of the 2B24 under the proper training program. Here the treatment should be cross referenced work by HUMRRO, i.e., Caro *et al.* It is of concern that this work on the 2B24 is not even referenced in Volume II.

5. The following value judgments are made on p. 33:

> "2B-35 visual attachment to the TA-4 (2F-90) simulator is not considered to be a useful device for landing training." "...the GE Compu-Scene...used by Boeing...is reported to be quite successful...." "The Air Force Flight Dynamics Laboratory... Redifon terrain model board...is one of the best installations of this kind in the country."

None of these are useful without an explanation of the features or specifications which are believed to be effective or ineffective.

6. Various limitation of current visual displays are identified, e.g., narrow field of view, low resolution and brightness, on p. 35. "All of these problems are receiving research and development attention and significant technical improvements are expected in the near future." It would be helpful to know what some of these are, whether they are regarded as feasible, when they might be expected, how much improvement is being promised, and whether the improvement are significant.

7. The summary on p. 36 implies detail and guidance that are not actually in the text, on how much improvement is worth having on such items as control anomalies, and improved visual image generation and display.

Attachment 2

8. On pages 37-38, a wide field of view and less time delays and lags are said to be needed for formation flight training. The magnitude of needed improvements or even a precise statement of current capabilities is not given.

9. What is really needed in the discussion on p. 43 is a quantitative description of the visual parameters required to improve simulators as well as a quantitative statement of the deficiency of present simulators. The idea that color is needed is unsupported by any data. The following statements need data to support them: "The visual capability to be required in a simulator used for ground attack training is related to the students' level of proficiency in the task." "...the 2B-35 visual attachment...a crude cartoon-like picture...has some utility in training novice students to become familiar with bomb range procedures, aircraft switchology..."

10. It is true as indicated on p. 65 that current ISD is based on estimates of the value of simulators rather than on demonstrated performance. That says the DoD will be better off when such data are available for ISD.

11. In the discussion of the G Seat on p. 78, the point should be made that if G Seats, which are apparently realistic, are to be useful for training purposes, experiments must be conducted to determine its value for training.

12. The discussion on pages 79 and 80 dealing with the value of motion systems are pure opinion but they are presented as fact. The same comment relates to the comment on the SAAC, p. 80, which states, "this simulator has less utility for training than some of the simulators without motion."

13. The listing of delay and lag values could be very useful in determining future requirements for training simulators and for correcting deficiencies on current simulators like the ASUPT and SAAC. This section, however, needs to be documented to include where and how the values are derived and what do they mean. For instance, what is the basis for the criterion "69% of the commanded response."

14. The deficiencies listed on pages 85-86 are useful in planning and evaluating the RDT&E program if they can be validated. By what process were the deficiencies generated, how serious are the deficiencies in quantitative terms, what performance is required to meet training for what missions?

15. Same comment relating to deficiencies in radar simulation on p. 87 and FLIR-LLLTV on p. 88.

16. The source for comments like the one on p. 91, that quotes the Navy budget for simulator maintenance as $125M compared to $40M for procurement, should be documented. The question of overall cost-effectiveness should be subject to experimental verification and analysis.

17. There is a very inadequate treatment of the central problem of transfer of training on p. 92 and also in the Executive Summary.

SPECIFIC COMMENTS ON VOLUME II

Simulation philosophy (p. 7-12)

This section summarizes the views of some who believe that simulators can be used to reduce the high costs of flight training, and of others who believe that effective flight training can only be accomplished in aircraft. It reduces these views about the use of simulators as either "substitute training" or "supplemental training". The real problem, of course, is to determine what combinations of training in simulators and/or aircraft produce maximum performance at various stages of flight training and proficiency maintenance after flight qualification. The issue is unresolvable without identifying the need for performance measures and of the types of data, under various combinations of training in aircraft and simulators, needed to tell us when and how simulators may be used to train flight personnel.

State-of-the-art (p. 12-19)

This section identifies the various problems thought to exist in the design of simulators with respect to visual display of the outside world, platform motion, cue interaction and performance measurement. The information can be more clearly presented if one master list is compiled. The section is not concerned, as titled, with state-of-the-art since it fails to describe quantitatively, the current performance characteristics obtainable in various simulators. This section should include those specifications plus the various improvements either desired and/or regarded as feasible, and are needed for adequate training.

The section does not include supplementary devices such as g suits and g seats, not the specific areas where, as reported by Gum and Swab (Learning Tech. Congress, 1976), simulators are adequate and where improvements are though to be feasible.

Transfer of training (p. 19-24)

This section correctly notes the many problems that have to be solved to conduct meaningful transfer of training experiments. It should summarize the findings of previous experiments and what experiments should be performed.

Training device concepts (p. 24-33)

This section lists a number of important features that appear in some simulators, e.g., problem freeze, record and replay, performance monitoring and adaptive training, and attempts to consider the cost-effectiveness of these various features. However, the purpose of the section is not clear. There is no effort to indicate which simulators had one or more of these features and which simulators, if any, with any of these features were regarded as superior to others without them. The report tries to summarize whatever information of interest appears in a series of reports. Suggest that the report list a number of key training features and then review reports which might or might not show that these features had value. One must, in general, accept the finding that little data are available. The use of the term "cost-effectiveness" in this section is purely cosmetic since no such relevant data are found.

Systems approach to training (p. 34-36)

This section criticizes SAT/ISD without bothering to explain what SAT/ISD is. These criticisms are vague and general, and the section would have better balance if it explained the improvements that SAT/ISD, whatever its limitations, brings to training compared to what was done before SAT/ISD was used to provide a systematic analysis of training.

Maintenance and improvement of skills (p. 36-37)

No data were found.

Cue fidelity requirements (p. 37-45)

This section attempts to address the issue of cue fidelity without specifying the degree of precision for the various cues being discussed or even the parameters that might be used to describe them. The authors report that motion can have a significant impact on crew motivation and that no motion appears to be better than poor motion for training applications, but they fail to describe the types of motion used in the experiments on which these conclusions are based, or the simulator or the subjects in the experiment. The section on vision that the report states that some studies were found on vision, but does not explain the circumstances of the experiments, the types of visual cues, or their precise characteristics; the important issue addressed seems to be time delays rather than visual or perceptual characteristics. "It is also somewhat obvious that many existing simulation facilities such as SAAC and ASUPT may be presently

inadequate for use as a facility to examine the effectiveness or fidelity requirements on many cues." (p. 45) The report fails to describe why these devices are inadequate, which cues are inadequate, is there any better equipment available, and what improvements are required.

<u>Simulator data requirements/acceptance evaluation</u> (p. 46-51)

Perhaps the major contribution made by this paper is to emphasize the importance of developing an adequate math model of an aircraft's flight characteristics in order to produce a valid simulation. The recommended solution to this problem is essentially an administrative one ("a properly coordinated team effort, with designated responsibility is essential to both obtaining a valid data base for the model and to provide acceptance testing," p. 50).

<u>Pilot survey on simulation</u> (p. 51-56)

Since pilots are the ones who have to use simulators, it is probably a good idea to know pilot views on simulators. Areas which lead to complaints should, at a minimum, be reviewed. Some pilots accept some characteristics while others do not. For example, in motion simulation, 70% think it is realistic, 30% unrealistic; in terms of motion requirements, 50% report that yaw is desirable and 50% undesirable; in terms of visual simulation, 70% found ground taxi, take-off, and landing realistic and 30% unrealistic. These data are difficult to use since simulators about which these pilots had favorable or unfavorable attitudes are not identified.

The following remark is not supported by anything which appears in the report:

> "The results of the surveys indicate that current simulation training may be most 'cost-effective' using part-task devices for standard procedural and emergency procedures training. This is somewhat enhanced by our previous discussion which indicates that it is procedural skills that are most easily forgotten." (p. 56)

<u>Full mission simulation (a case history)</u> (p. 56-59)

This section examines RAF experience with the Phantom Full Mission Simulator by reviewing reports on it issued in 1970, 1973, and 1975. It finds that the procurement was based on subjective assessment and that operational experience did not show that the desired goals were being achieved. The finding is probably a realistic one. One case

history is better than none, even if it refers to a failure. It would be even better, however, to have two case histories than one. For instance, the successful use of flight simulators by the airlines would provide a more balanced review.

TAC ACES I and II (p. 59-63)

The purpose of those studies is not given nor the type of data collected, number of subjects, or anything which would permit one to judge whether the conclusions, as summarized, are supported by anything given in the reports. There is one notable exception to this remark:

> "The recommendation reached on this program concerning the necessity for motion, based on false cues presented by the SAAC motion system is an over-generalization. The only appropriate observation is that no motion may be less distracting and bothersome to the pilot during ACM training in a simulator than the existing SAAC motion system and associated drive logic." (p. 62)

The following conclusion, however, is doubtful, "At best, the simulator can provide supplementary training but cannot be used (based on pilot comments) as a substitute for flying time, based on the technology used in VACS and SAAC." (p. 63)

A-10 Aircrew Training Device Trade Study (p. 63-67)

This is the only thoroughly critical review in this report. It doubts that the A-10 study findings are valid by questioning its assumptions about utilization (5000 hrs/cockpit/yr) and its availability rate (100 percent). However, the treatment would be more useful to the DoD if the report summarized the A-10 results and then proceeded to critique them. At present, the argument is not easy to follow.

U.S. Navy UPT Task Analysis (p. 67-70)

This section is an uncritical summary of a questionnaire survey in which pilots (experienced fleet aviators and second-tour aviators in operational squadrons receiving newly designated pilots for additional training) were required to rate specified UPT tasks in terms of frequency, criticality and training adequacy. These data are not reported and the extent to which the pilots agreed or did not agree in their views is not reported. What are reported are the changes from current practice in the numbers of hours assigned to training in flight and in simulators during basic, jet intermediate, and jet advanced training. It is impossible to judge whether or not these changes make sense.

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES AIR FORCE
WASHINGTON, D.C.

REPLY TO ATTN OF: XOO

SUBJECT: CALSPAN Simulator Study, Contract MDA-903-76-C-0204

TO: OASD/P&E (TACAIR)

1. Volume I of the subject study has been reviewed as requested; Volume II has been forwarded to various Air Force offices and comments will be provided at a later date.

2. The subject report contains an extensive amount of information, some of which is meaningful. However, the report in general is of limited value due to its basis of personal interviews without supporting data.

3. Provided in the report is a summary of the role of simulation in military tactical flight training, the state-of-the-art in some areas of simulator technology, and some insights into future research requirements. Detailed discussions of the individual simulators which highlighted deficiencies or inadequacies of current simulators should acknowledge that the simulators in question represent a technology which is over a decade old, and a corresponding training philosophy which influenced their design.

4. Although some of the observations are clearly open to challenge, as indicated in the attached specific comments, it is not surprising they appear, given the wide variety of opinions that exist in the simulator world. The real danger of this report lies in a possible assumption that the assessments are based on in-depth analysis. A reader may become absorbed in a report seemingly based on rigorously achieved scientific data and ignore, or soon forget, that the authors' stated methodology was an interpretation of survey interviews.

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5. We believe Volume I's primary research basis of interviews without substantiating data is inadequate to completely fulfill the study objective.

FOR THE CHIEF OF STAFF

1 Atch
Specific Comments

Cy to:
OASD/M&RA, Lt Col Junkmann
OASD/I&L, Mr. Howard Ellsworth

SPECIFIC COMMENTS ON CALSPAN REPORT

Page 1 - Executive Summary

The study is titled, "An Assessment of the Role of Simulators in Military Flight Training." From the title one would infer that the study is a complete assessment of military flight simulators. However, as stated in the introduction, the assessment is limited to tactical flight training. The title should be changed accordingly.

Page 2 - Emergency Procedures

We agree that too many emergency procedures capabilities may have been procured. However, the criterion for procurement is training requirements and not, as the CALSPAN report recommends, "the number that can be accommodated in the training schedules."

Page 3 - Aerial Refueling

Aerial refueling capability is currently available in the AWACS Flight Simulator at Tinker AFB. New simulator procurements such as the F/FB-111, B-52G/H, C-5, and some models of the KC-135 will also include aerial refueling capability. It is anticipated that this capability will avoid some basic aerial refueling flights as well as supplement current training.

Page 5 - Air Combat

Deficiencies of air combat simulators are listed without reference to the specific technology to which they apply. For example, dome and optical mosaic are two types of visual display technology, and have different limitations. (Page 5, 6, 85, and 86).

"Poor altitude cues" are generally confused with "poor altitude change cues." Pilots in actual flight find visual determination of absolute altitude haphazard at best. They can, however, sense altitude changes and rates of change in both the real world and in the SAAC. Furthermore, the phenomenon of flying one's air-to-air combat opponent into the ground is not unique to SAAC. The emphasis should be on the ability to detect altitude changes for air-to-air training rather than to determine a specific altitude. (Pages 5, 6, 8, 49, 85, and 96).

Page 6 - Air Combat

The statement is made "that these simulators will permit supplementing air combat training, but will probably not permit any significant reduction of air combat training in the aircraft.". This conclusion is not supported by data.

Page 7 - Full Mission and/or Part Task Simulators

While the ASUPT is difficult to fly in the formation mode, a recently completed study indicated that a training effectiveness ratio of 1:1 was achieved for the first two hours in training UPT students in formation flying.

The problem with ASUPT was not that it was conceived as a full-mission simulator which caused tradeoffs that reduced iteration rates. ASUPT was not conceived as a full-mission simulator. The ASUPT design philosophy was one of bringing together the best that technology could offer during the early 1970s to explore the maximum effective use of modern simulators in UPT. It was recognized during its design formulation that it would have severe limitations in some UPT mission areas such as night flying and cross-country flying. Obvious compromises were made between cost, performance capability, and technology compatibilities.

There was not a lack of appreciation for the importance of time delays. The visual system transport delay was recognized and a time compensation technique was developed before the visual system and system integration contracts were awarded. As a matter of fact, those responsible for the development of ASUPT were the first to recognize and publicly report (AIAA Visual and Motion Simulation Conference, 26-28 April 1976) problems associated with visual and motion system delays in simulators. In addition, those delays are not unique to ASUPT, but are inherent in all other training simulators (excluding those currently under development which have profited from the ASUPT experiences) and some engineering simulators, e.g., LAMARS.

Page 7 - Supplement or Substitute

Future flying hour programs will be developed based on a critical analysis of operational concepts for the particular weapon system and the function of all crewmembers in that system. Included as an integral part of the analysis will be the benefits expected from aircrew training devices. Aircraft flying training will be supplemented with simulators in those areas where it is not practical or possible to train in the aircraft, and substituted as much as possible, consistent with maintaining aircrew readiness and the readiness of supporting elements.

Pages 7 - 10

All problems noted in these pages are common knowledge in the R&D community and are being addressed at levels of effort commensurate with their priorities and available resources. As a case in point,

there are a number of problems yet to be resolved before a FLIR or LLLTV simulation is ready for inclusion in a training simulator. Some of these problems are being addressed by AFHRL as high priority efforts, e.g., degree of simulation fidelity required and relative efficacy of LLLTV and FLIR under varying seasonal and geographical conditions.

Page 9 - Certification, Modification, Revalidation

The Air Force has developed a simulator certification program (SIMCERT) which will provide parameters to be used in evaluating training device performance. It will be determined if the device performs to its originally designed specifications; and if not, it will enable the determination/identification of the deficiency for prompt corrective action. Additionally, the SIMCERT effort will validate the tasks that can be adequately trained in the simulator.

In respect to aircraft changes, modifications are continually monitored to assure that any modifications which impact training are incorporated in the simulator.

Page 10 - Software Management

Single software support centers for control of simulator software are being established at various bases. There will be a single support center for each major weapon system.

Page 10 - Transfer of Training

Actual transfer of training will be determined during the SIMCERT program. Air Force flight management regulations have been changed to allow the crediting of either aircraft or command certified simulator time to meet flight activity requirements.

Page 13 - Background

The requirement for a 25% reduction in flying hours was contained in the FY77 Planning, Programming, and Guidance Memorandum from DOD.

The Senate Armed Services Committee Report for FY76 states, "The committee wishes to make it clear that it supports the DOD program efforts to achieve a 25% reduction in flying hours and a saving of energy resources with the increased use of simulators and training devices. However, the committee will not tolerate any degradation in the quality of the flying force from the use of these devices as a substitute for flying."

3

Page 28 - 30 - Instrument Flight

The comment is made that flying proficiency cannot be developed using simulators. This comment is contradictory to research data developed by the Air Force Human Resources Laboratory as well as others. Perhaps "flying proficiency" needs to be clearly defined.

This section contains the first of several instances where CALSPAN makes unsubstantiated declarations regarding reductions in flight time.* The implication is that the balance between simulator and flight time is being reversed too rapidly, and is not only wrong, but extremely risky. The conclusion that "the students need the in-flight experience gained by the flights that were cut out," after a training study apparently led to an operations decision to reduce flight time, is not for CALSPAN to judge without data to support their contention. Such an unfounded conclusion tends to make the credibility of other CALSPAN comments in this report suspect. (*Page 30, second paragraph, page 7 second paragraph; page 54 second paragraph.)

The comment regarding psychological factors not at play in the simulator, such as risk and danger to life, leading to students becoming panicked during their first RTU IFR flight is not documented.

Air Force F-4 simulators were designed (in the early 1960s) for transition and continuation training of experienced operational pilots. In 1969, a Variable Anamorphic Motion Picture (VAMP) visual system was added to F-4E #5 which revealed previously unnoticed deficiencies in the flight program. Based on pilot comments, these deficiencies were corrected yielding a simulator that represented the F-4 aircraft fairly well. Consequently, this revised flight program was inserted into all the Air Force F-4 simulators. Authorized modifications should only improve/upgrade the simulator to match an ever changing aircraft. Each aircraft change is reviewed by the responsible organization for possible inclusion in the simulation. Luke AFB is the designated base for initial insertion and checkout of ECP kits. After acceptance, the kits are installed in the remaining simulators. Thus, the flight program should still adequately represent the F-4 aircraft.

Not acknowledged in the report is the fact that the F-4 simulators being commented on represent both a decade old state-of-the-art engineering and a ten year old training philosophy which influenced the design.

4

Page 33 - Takeoff and Landing

It is the understanding of the Air Force that the 2B-35 visual attachment to the TA-4 (2F-90) simulator is a useful device for landing training. When it was incorporated into the training program, a reduction of three flying syllabus hours was realized.

Page 34 - Takeoff and Landing

The unpredicability of lags and delays of the various simulator subsystems prevents quantification of these type problems prior to total system integration. After integration, schedule and cost limitations hinder efforts to completely resolve lag and delay problems, therefore leading to simulator tradeoffs.

Page 35 - Takeoff and Landing

The statement that the training community may not appreciate, or is only recently discovering the importance of lags and delays, is not accurate. As a result of development work on the ASUPT, these problems have been well defined and reported. ASUPT is also the first system to use techniques for compensating image generation transport delays.

Page 37 - Formation Flight

The comparison of the Advanced Simulator for Undergraduate Pilot Training (ASUPT), the Simulator for Air-to-Air-Combat (SAAC), and the Formation Flight Trainer on the basis of their formation flight simulation capabilities and their costs is an invalid comparison. All were designed and built for different purposes.

The reason the SAAC cannot be flown in close formation is that the other aircraft image does not change size or perspective inside 100 feet which is an intentional design limitation since the SAAC was designed for air combat and not formation flying.

Page 38 - Aerial Refueling

Aerial refueling capabilities have been commented on previously in remarks associated with page 3.

Page 44 - 45 - Ground Attack

Project 2235 used four simulator facilities during evaluation. The Navy's 2B-35 visual attachment at Beeville Naval Air Station is the fourth facility. While passing reference is made to Project 2235, no serious attempt was made by the researchers to establish contact with Project 2235 management, engineering, or test personnel. Use of Project 2235 data, which is recent, as opposed to concentrating on F-4 simulators, which are older technology, would have been

more germane to the study.

Comments concerning Project 2235 should be amended to reflect the findings of the study.

ASUPT can provide air targets and terrain simultaneously; however, the level of detail is dependent upon the allocation of the available computer-generated image edges.

Page 46 - Ground Attack

The authors are inappropriately trying to apply data from a one-of-a-kind research device to production items. The ASUPT availability figures cited are incorrect. The correct figures could have been obtained if they had been requested.

The authors also state that based on interviews, the "operational availability" of the F-4E #18 and SAAC simulators was "of the order of 30-40%." Since no definition of "operational availability" is given, this statement has little meaning. The SAAC was designed as an R&D device rather than as an operational trainer, and both the SAAC and F-4E #18 were the victims of poor maintenance programs until just recently. The use of their availability rates to imply that future simulator procurement quantities are understated by a factor of more than two is probably one of the gravest errors in the report.

Page 47 - Ground Attack

The report is correct in recognizing that Mission Ready (MR) is not rigorously defined. Definitions of MR have been defined as the result of what training could be accomplished during peacetime. TAC is redefining mission ready based upon what the crew will do in combat. This will specify what knowledges, skills, and attitudes MR aircrews must have to be effective in combat. Thus, we can specify what training can be accomplished in flight and what must be done in simulators because of safety and peacetime constraints. Such tasks as SAM avoidance, AAA tactics, dogfighting below 1,500 feet AGL, etc., will be practiced in the simulators. The result of such simulator training should be an improved combat potential of our tactical air forces.

Page 48 - Ground Attack

The report states that if the A-10 meets expected utilization rates of 38 hours/month then the need for the A-10 full mission simulator identified in the A-10 trade study may not be

required because the training can be done in the air. Do the report authors expect the Air Force to train crews in ground attack at 2000 foot ceiling and visibilities less than two miles in the air? Do they expect A-10 pilots to practice SAM and AAA counters in the air? Who will provide the quantity of moving tanks required to be attacked by A-10 pilots (in 2000' and two miles) to be effective in using its tank destroying gun? The simulator identified in the trade study will.

The aircraft utilization rates used by the authors to make their point about A-10 training is completely invalid. To compare the utilization rates of Navy Trainer aircraft with an operational A-10 is not reasonable.

It is true that much of the simulation capability described in the Master Plan is beyond the current state-of-the-art. The purpose of the Master Plan is to identify areas of deficiency so that an orderly, systematic attack can be made to overcome them.

Page 50 - 59 - Air Combat

It has not been shown that it is necessary to duplicate all the effects of load factor on the human body. One of the objectives of simulation is to provide to the pilot those cues necessary for training. A detailed objective study is needed to determine which cues are necessary, the best methods of providing these cues, and the fidelity of replication required.

The Differential Maneuvering Simulator (DMS), the Large Amplitude Simulator/Wide Angle Visual System (LAS/WAVS), the Vought Corporation's simulator used for the TAC ACES programs, and the various models of the Manned Air Combat Simulator (MACS I-IV) are primarily aircraft engineering design tools. SAAC is primarily a training research tool that is being used as an operational training simulator, and ASUPT is a training research tool. Although each can provide some of the visual cues necessary for air combat training, only SAAC was designed for that purpose.

Page 52 - 54 - Air Combat

The comments that the simulator program was an aid to the student but did not show one way or the other whether flight time could be reduced reflect inconsistencies or inappropriate evaluation strategies. If it could not in fact be determined that any flights could be eliminated, how was it determined that the advantage of the simulator experience washed out after eight tactics hops?

7

Regarding the comments on the TAC ACES program, we have long recognized the limitations as well as the potential capabilities of the Vought Air Combat Simulator and have in each year's contract included appropriate software and hardware modifications to minimize these limitations. By the time ACES I training resumes in January 77, an entirely new target image generation and display system will have been installed as well as a programmable stick force loader and improved weapons scoring logic. These mods are expected to give the device an image resolution and fidelity matching the real world (yet with the ability to tailor image prominence to the specific training exercise) and to provide much improved flight control realism. TAC has no data to support the suspicion on page 54 that ACES training has caused graduates to over G aircraft.

Another area of the report which is very subjective is the discussion of the McDonnell Aircraft Corp simulators (page 54). The details and capabilities of the MACS simulators are accepted at face value through discussions without a review or actual use such as was done on every other simulator.

Page 57 <u>Air Combat</u>

The comments on psychophysiological problems associated with the SAAC appear to be taken out of context. The problems appeared during the missions but were debriefed and evaluated after the missions. A complete discussion of these problems appears in "Evaluation of the Simulator for Air-to-Air Combat" FOT&E Phase I Report, June 1976. We have been unable to substantiate the report that "One squadron commander has directed that pilots cannot fly a real airplane within 3 hours following a simulator session."

The TAC ACES II is in operation now with an in-commission rate of 70 to 80% for July 1976 through October 1976. Many of the problems with the SAAC can be traced to an inadequate control loading system.

Page 58 <u>Air Combat</u>

In May 1976, the Project 2235 Evaluation indicated that the target aspect could be determined to at least three miles for the SAAC.

ASUPT may be configured for air-to-air combat simulation with respect to being able to fly one-on-one; however, this is just a fallout of its formation flying capability. The visual system

8

was designed for formation flying, not air-to-air combat. Its resolution which is about seven arc minutes renders the lead aircraft unusable beyond about one-half mile.

The AIAA paper states that the SAAC motion system delays were about the same as ASUPT, not 267-400 ms.

The ASUPT and SAAC designs were the result of resource constraints and direction to use off-the-shelf motion systems, not a lack of appreciation of the importance of time delays. The low iteration rate causes only about one-third of the total motion system delay. Increasing the iteration rate to 30 Hz would reduce the total system delay by less than 17 percent.

Increasing the iteration rate will not affect the average ASUPT visual system delay. Also, ASUPT's visual system delay is less than any known simulator, be it training or engineering.

Page 60 - Non-Pilot Crew Stations

CALSPAN cites criticism by Navy operators, instructors, and students of the F-14 weapon system operator simulator "not being adequate to be used for the entire training syllabus." It must be pointed out that the F-14 weapons operator station (and pilot station) was never designed to handle all training tasks within the syllabus. It is a weapons system trainer specifically designed and configured with the capability to simulate mission oriented tasks only; *normal checklist and startup/turnoff procedures* can be trained much more efficiently on PTTs/CPTs.

Page 64 - 65 - Supplement or Substitute

See comments previously provided in respect to this same question on page 7.

The observation that Air Force and Navy pilots were unanimous in stating that flying hours have been cut to the point that operational readiness cannot be maintained requires clarification. No support for the statement has been found, and TAC staff members are adama ' that no such statement was made during the CALSPAN team visit to TAC headquarters.

The comments concerning the ISD processes (pages 64-65) as they relate to simulator design need to be clarified. The reason we are in the fix we are today with the current simulators (including the F-15) is because our simulators were designed by engineers to duplicate the aircraft as closely as possible within a very low budget. It was only after the simulator was delivered that the trainers could find out what it could do and then develop ways to use it in the training program. The comments by the officer

(3rd para, page 64) on the future use of ISD to design a training program which will include the proper mix of training including the simulator is the essence of ISD.

The quote taken from CALSPAN Report No. FE-5558-N-1, B-1 Systems Approach to Training Technical Memorandum SAT-1 is incorrectly quoted. The referenced statement should have stated that "SAT is no panacea for training system development...."

The statement that training programs developed by ISD methodology involve judgements of the value of simulator training relative to in-flight training and therefore "there is no way to be sure the proper mix of training will result" is correct. However, that should not be construed as a criticism of ISD. The ISD process takes such a situation into account by requiring careful, evaluative iterations over the total service life of the instructional system (validation phase). The R&D community eventually hopes to develop a taxonomy of equipments that will be assigned a transfer of training value by task.

Page 77 - Fidelity of Aircraft Simulation

Regarding availability of aircraft aerodynamic data, the cited data problem is applicable to all types of data. The study is being done for the Aeronautical Systems Division's Deputy for Development Plans.

Page 79 - Motion and Force Cueing

The comment that AFHRL studies are not held in very high regard should be deleted unless the comments can be substantiated. The opinions of a few should not be taken as factual when others disagree.

Page 80 - Motion and Force Cueing

The Large Amplitude Multi-Mode Aerospace Research Simulator (LAMARS) does have target image generation capability and its primary use is as an aircraft engineering design tool for use in the air-to-air regime. Therefore, the conclusion about LAS/WAVS being the only simulator available to study motion cues is false.

Page 81 - Motion and Force Cueing

In addition to the areas noted, there is need for research and development of force cueing devices which should include basic research on the human sensory mechanism to establish which cues are needed and the fidelity of replication required.

Page 83 - Time Delay and Lag

These time delay comparisons are inaccurate and misleading and indicate that the authors do not seem to understand the subject of simulator delay.

The compute and output delay for the 40/sec, 33/sec, and 20/sec cases should be doubled. Also, CALSPAN does not include time in its analysis for the software drive algorithm which is the major cause of motion system delay. For their analysis of a typical engineering simulator (33/sec) the total delay would be approximately 266-296 MSEC, if analyzed properly. This means that even in the typical engineering simulator, the motion delay is only about 25 percent less than ASUPT. The ASUPT visual system delay is less than the typical engineering simulator.

Page 84 - Visual Image Generation and Display

Image contrast should be included in the visual system deficiencies list because image brightness and contrast are intimately related.

Page 87 - Radar Simulation

The Air Force is also devoting much effort to radar landmass simulation. Further, the image display error example is misleading. It does not discuss all pertinent factors, not does it point out that the same example applies to any system identifying aircraft position.

Page 92-93 - Transfer of Training

This is a very short and inadequate treatment of a complex subject. In fact, it has negative implications when it deals with the difficulty of conducting training experiments and the impact upon career advancements and safety. Admittedly, safeguards must be exercised, but transfer of training studies must take place, and be measured, if the potential benefits of simulation are to be understood.

The discussion on "transfer of training," in general, leads one to suspect that the authors are not aware of what is currently known about the elusive concept of transfer of training. The research literature does reveal substantial information, supported with replicated laboratory studies, regarding transfer of training (TOT). Unfortunately, TOT investigations within the area of aircrew training applications have been too expensive to pursue. Traditionally, R&D in the behavioral sciences has been underfunded with the net result being incomplete, "on-again, off-again efforts

which also cannot afford the required investigative apparatus to research the TOT issue with any semblance of continuity. With the organization of AFHRL and development of the Advanced Simulator for Undergraduate Pilot Training (ASUPT), the Air Force is now in a position to exploit its newly acquired research capability. The AFHRL has already demonstrated dramatic improvements in student pilot learning rate (sorties to reach criterion performance) through use of the ASUPT device over the old pilot training program which had no simulators.

The weakness expressed in terms of objective performance measurement definition is not a problem with the ISD "approach" as much as it is in implementation, or the difficulty on the part of the curriculum developer to identify what level of performance he expects the trainee to identify in definitive terms, e.g., the criterion level of performance that must be met to demonstrate successful accomplishment of air-refueling.

The Air Force is using ISD to design an instructional system supporting a weapon system which will produce mission ready qualified crew members who will be made available to field commanders in the least time and cost. To achieve that goal all devices (including the simulator) used in the training program should be designed as a result of what they are expected to do in the training program. ISD cannot function totally without any subjective decision processes but it attempts to make as much objective material available to training managers, supervisors, and engineers as possible prior to necessary subjective decisions. What ISD will do is identify the training requirements (tasks, task factors, cues, stimuli and the correct responses - CRO) from which the engineers can design and produce simulators which will be a coherent part of the instructional system.

Page 95 - SAAC Simulator

The SAAC does not contain a two dimensional model as noted in the report. What is provided is a two dimensional view, in true perspective, of a three-dimensional gimballed model.

The hardware and electronics were designed so that the target does not change size or perspective inside 100 feet. This range is well inside the minimum range required for air combat.

Throughout the study, numerous references are made to CALSPAN test pilots flying the simulators. The impression given by the report is that the pilots are experienced in the type aircraft being simulated. Yet, nowhere are the pilots' experience and training expertise cited, nor is there any mention of the type

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of profiles flown. Therefore, the appropriate weight of their impressions in the context of assessing the simulator's value for aircrew training is difficult to judge.

Page 97 - Williams ASUPT

Experienced T-37 pilots at Williams do not agree with this assessment. It is possible that the lack of recent flying experience with the T-37 or the small exposure to the simulator could explain the reported impression.

DEPARTMENT OF THE NAVY
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
WASHINGTON, D.C. 20350

IN REPLY REFER TO
Memo 593/688
26 NOV 1976

MEMORANDUM FOR THE DIRECTOR, PLANNING AND EVALUATION, OFFICE OF THE SECRETARY OF DEFENSE

Subj: CALSPAN Simulator Study Contract MDA-903-76-C-0204

Ref: (a) OSD, Office of the Director, Planning and Evaluation Memorandum dated 4 November 1976

Encl: (1) Aviation Training Device Requirements Branch, OP-596 Memorandum dated 26 November 1976

1. The CALSPAN Simulator Study has been reviewed and the following comments are submitted as requested by reference (a).

a. The CALSPAN Study "An Assessment of the Role of Simulators in Military Flight Training" provides an interesting, unsophisticated insight into the practical acceptance of military flight simulation at the operator level. Although some fault may be found with the methodology in Volume I, this survey reveals the difference between the state-of-the-art simulation capability that is addressed at senior levels as compared with the capability that is experienced in the field.

b. Volume II "Assessment Based on Literature Survey" directed specific attention toward the data available on the use of flight simulation for tactical flight crew training. The alternatives to the use of simulation found on page 72 were of particular interest, particularly the recommendation that a more careful assessment be made of relatively low cost part task trainers utilizing existing state-of-the-art technology.

2. In conclusion, these volumes provide an interesting assessment of the state of flight simulation available at the present time. A prime value of this work is that it tends to balance the current enthusiasm which overwhelmingly supports flight simulation in all applications. Specific comments on Volume I by the Aviation Training Device Requirements Branch (OP-596) are attached as enclosure (1).

O. G. Elliott

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Head, Tactical Air
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DEPARTMENT OF THE NAVY
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IN REPLY REFER TO
26 November 1976

From: OP-596
To: OP-593

Subj: Some specific comments on the CALSPAN Study "An Assessment of the Rose of Simulators in Military Flight Training" Vol I

1. Volume I, Section I, Executive Summary. The Executive Summary is replete with editorial assumptions which should be stricken from the final report. Among those recommended for deletion are the following:

a. Page 1, Instrument Flight. Sentence, "They do not, however, represent . . . instrument training and experience in the airplane." Comment: It is not the intent of the services to "eliminate" instrument training in aircraft, but, rather to determine the best aircraft/simulator mix, as recommended in the next sentence, same paragraph.

b. Page 2, Instrument Flight. Sentence, "Motion system judged . . . this type simulator." (emphasis added) Comment: Although the statement is no doubt true, the assumptions on which the judgment were based were not necessarily couched in an understanding of training effectiveness evaluation.

c. Page 6, Air Combat. Sentence, "These simulators will permit supplementing air combat training but will probably not permit any significant reduction of air combat training in the aircraft." (emphasis added). Comment: Assumption.

d. Page 28, Instrument Flight. Sentence at the bottom of the page, "The simulators, however, do not fly . . . and proficiency developed." Comment: Assumption not based on an evaluation of training effectiveness.

e. Page 33, Takeoff and Landing. Sentence mid-page, "For example, the 2B35 . . . is not considered to be a useful device for landing training." Comment: The so-called "test pilot" states on page 96 of the report that he could not judge altitude adequately well to determine when to "flare". The comment is not germane to Navy TA4 training, since all landings are mirror passes and the pilot flies the aircraft "to the deck", i.e., no flare.

f. Page 41, Recovery from Uncontrolled Flight. The comments are concurred with, but the reference to the F-7U, an aircraft that has been out of the inventory for almost twenty years, is begging the question.

g. Page 91, Certification, Modification, Revalidation. The Navy has a comprehensive Quality Assurance and Revalidation (QA&R) program that responds to the need for periodic evaluation of trainer material condition. In November 1976, the Navy published OPNAVINST 10171.6 establishing doctrine and procedures for the conduct of aviation training device certification.

2. This is only a brief, partial review of the study, but should suffice to indicate the degree of concern we have for its validity.

Very respectfully,

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